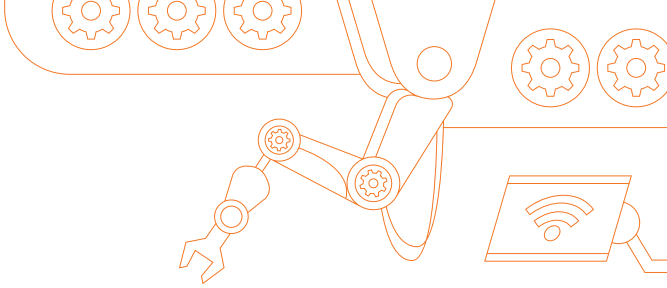
KIRTANE & PANDIT

LIGHTS OUT

Powering India's Future With Smart Manufacturing

September 2025

Contents



01. EXECUTIVE SUMMARY

In 1955, Philip K. Dick wrote a science fiction story, Autofac, about a network of self-replicating robot-automated factories set up to supply food and goods to a handful of human survivors. Today, lights-out manufacturing (also called dark factories since machinery can operate with the lights out) is no longer science fiction. Since 2001, at FANUC's robot manufacturing facility in Japan, robots have been used to produce robots. The factory produces around 6,000 robots a month, and can run for up to 30 days with zero human supervision, with even the air conditioning and heat turned off.

In 2025, India overtook Japan to become the fourth-largest economy in the world, and is also the third most sought-after manufacturing destination in the world, with the potential to reach USD 1 trillion by FY 2026. Many strategies favour India's digital transformation in the manufacturing sector, for example, the China Plus One strategy, which has led major electronics firms such as Apple, Samsung, and Foxconn, to establish manufacturing facilities in India. India has achieved an 85% reduction in mobile phone imports, with a 200% increase in manufacturing jobs from 2022 to 2024.

India's automotive sector is also now the fourth-largest in the world. Globally, the automotive segment is the largest end-use for lights out manufacturing. Demand for industrial robots from India's automotive sector went up 139% in 2023. These sectors, together with sectors such as pharmaceuticals and semiconductor manufacturing, are the key sectors experiencing a shift to automated manufacturing across the world.

Lights-out manufacturing is a natural extension of Industry 4.0, which integrates advanced manufacturing technologies by connecting machines with real-time information and communication technologies. By leveraging Industry 4.0 technologies and advancements in cutting-edge technologies such as robotics, artificial intelligence (AI), digital twins, Industrial Internet of Things (IoT), and Additive Manufacturing, lights out manufacturing represents a transformative production methodology where factories can function 24/7 with minimal or no human intervention. Many industries, ranging from electronics to automotive, are increasingly adopting this approach to reduce labour costs, enhance product quality, and meet escalating production demands.

The shift to a lights-out manufacturing process can potentially save up to 20% of labour costs and increase productivity output by around 30%. The lights-out setup enhances efficiency, reduces operational costs by functioning with minimal human operators, eliminates human-related errors, reduces the risk of worker safety, and improves environmental sustainability. According to markets.us, a market research platform, the global lights-out manufacturing market size is expected to grow from USD 47.3 billion in 2024 to USD 94.8 billion in 2034, reflecting a Compounded Annual Growth Rate (CAGR) of 7.2%.

In 2018, the World Economic Forum launched the Global Lighthouse Network with 16 'lighthouse' companies, i.e., leading companies across the world that implemented advanced 4IR technologies in manufacturing. As of January 2025, there are 189 lighthouse companies in the world. India's CEAT and Unilever factories became the latest Indian companies to join the World Economic Forum (WEF) network of lighthouse companies in 2025.

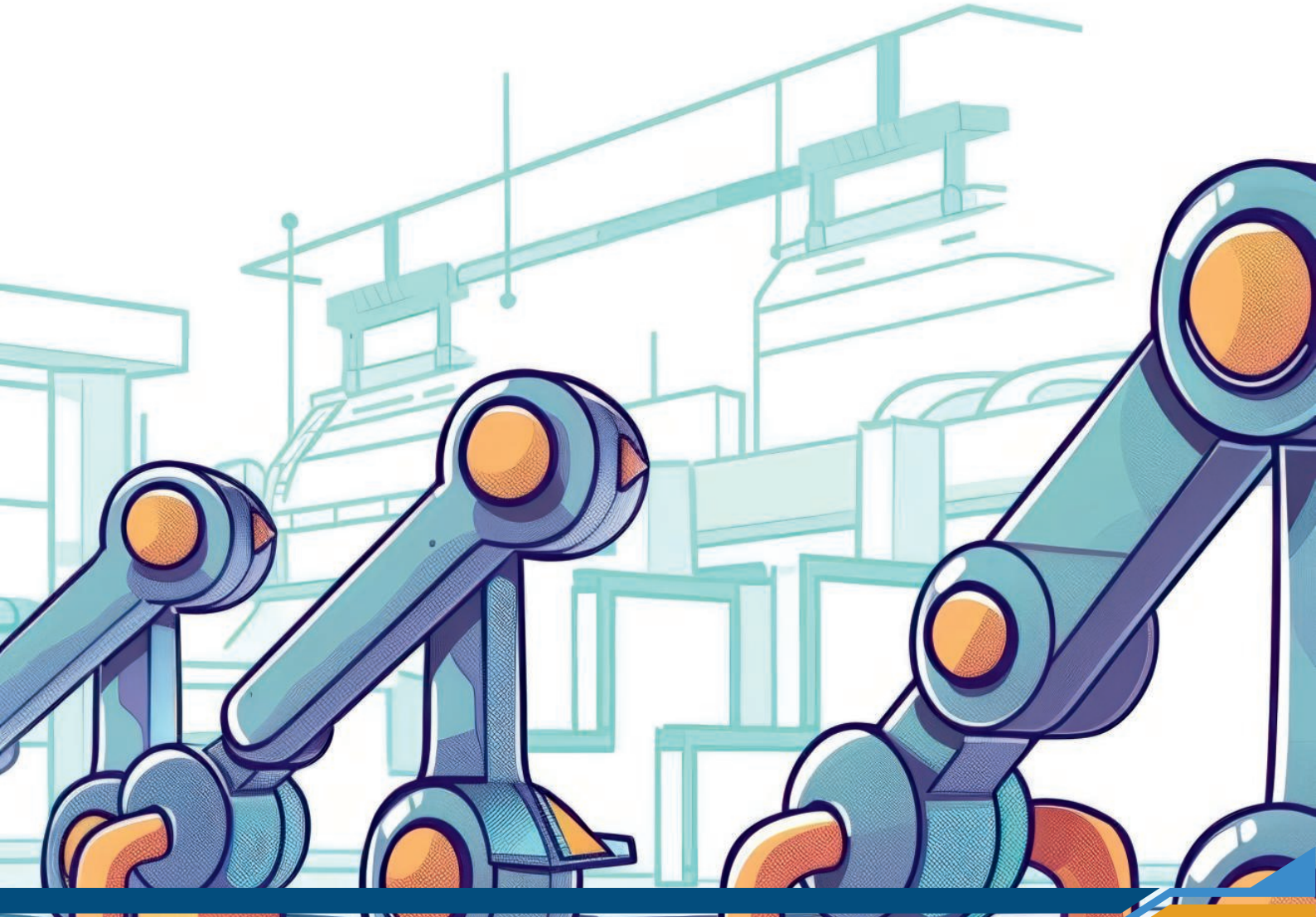
During the COVID-19 pandemic, facilities with lights-out capabilities were able to maintain production levels during the lockdowns, unlike traditional factories. Following the pandemic, many companies began making major investments in automation. According to the World Economic Forum, "2020 was the year that automation started taking over the workforce". While the adoption of fully lights-out processes in 2025 is still rare, many companies are rapidly making the shift to smart manufacturing and the adoption of Industry 4.0 technologies. As of 2023, 67% of industrial manufacturing companies have initiated a transition to smart manufacturing.

The Asia-Pacific region dominates the lights-out manufacturing market with a 44% share in 2025, driven primarily by growth in China, Japan, and South Korea. The market size of India's industrial automation market is estimated to grow from USD 17.28 billion in 2025 to USD 33.64 billion by 2030, reflecting a Compounded Annual Growth Rate (CAGR) of 14.26%. Government initiatives such as Make in India, Digital India, and the Production Linked Incentive (PLI) scheme have provided a growth boost to India's manufacturing sector.

However, despite its potential, fully automated manufacturing is still in a nascent stage. Notable challenges include high capital investment, integration with complex technologies, and a lack of a skilled workforce to manage and maintain sophisticated systems. There are also growing concerns over the loss of jobs and the scalability of automated systems. With respect to India, significant challenges include poor logistics and transport, limited domestic AI compute, low digitization according to users, infrastructure gaps with respect to the supply of electricity and internet.

India's target of achieving a 25% contribution to GDP from the manufacturing sector by 2025 has not been met, with the sector contributing around 13-14% to GDP as of 2025. Further, India's share in global manufacturing stands at 2.8%, as compared to China's share of 28.8% (which is projected to increase to 45% by 2030). 90% of India's manufacturing companies are small and medium-sized enterprises (MSMEs), which are operating with outdated technology and facing financial and technological constraints. Considering these hurdles, MSMEs in India may consider implementing partial automation across production processes or consider a lights-sparse model instead of a full lights-out production setup.

In this report, we provide a comprehensive analysis of lights-out manufacturing, industrial automation, and the global transition to smart manufacturing, including connected segments such as factory automation, smart manufacturing, implementation of Industry 4.0 technologies, industrial robotics, and AI in manufacturing. The report also includes detailed case studies and strategic insights for businesses interested in beginning the transition to automated manufacturing, as well as the benefits, challenges, and future prospects of this transition.

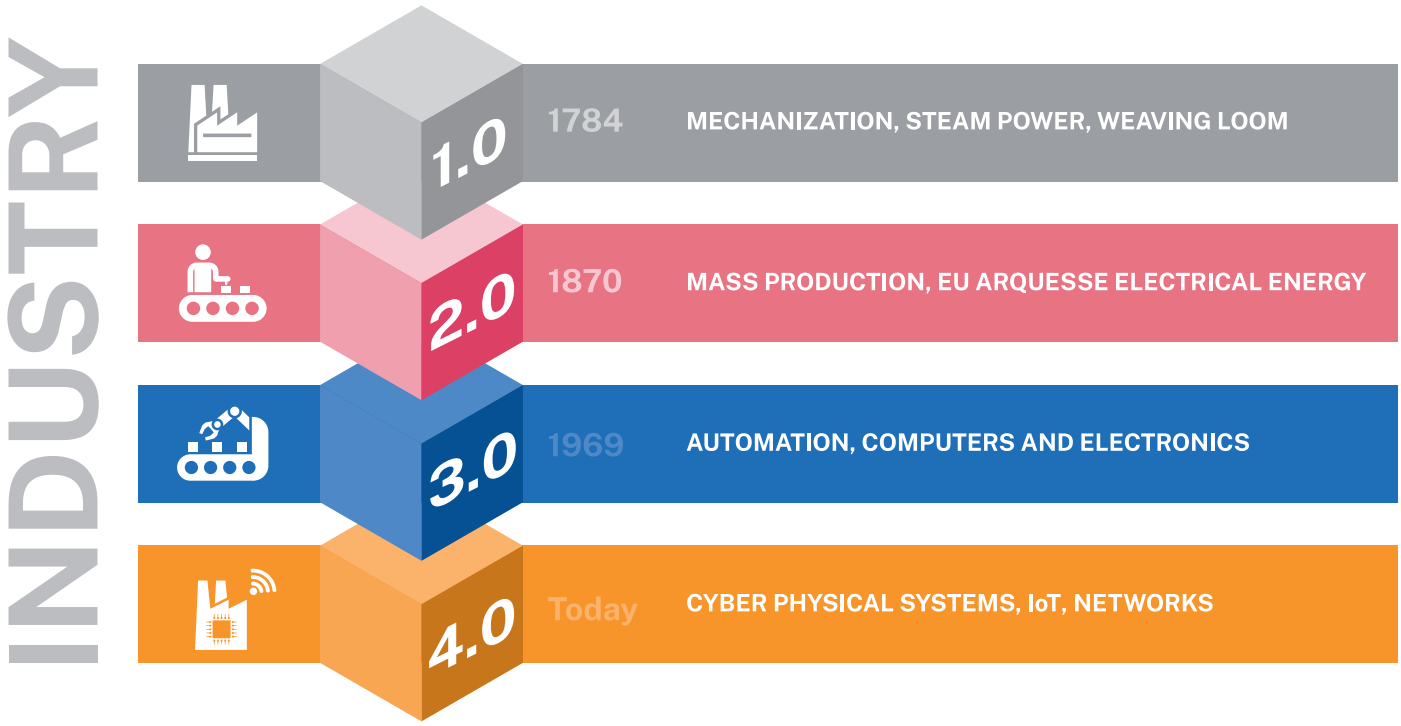


02. INTRODUCTION

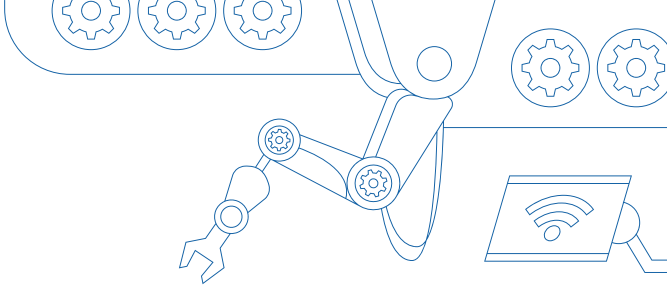
2.1 What Is Lights-Out Manufacturing?

Lights out manufacturing, also known as a dark factory or fully automated manufacturing,refers to manufacturing processes that run entirely without human intervention – so termed since these factories can run 24/7 with the lights off and without any heating, ventilation, and air conditioning (HVAC).

Lights-out manufacturing is the next phase in the Fourth Industrial Revolution (Industry 4.0 or 4IR), which refers to the intelligent networking of machines and processes for industry with the help of information and communication technology. Industry 4.0 employs advanced technologies such as artificial intelligence (AI), Cyber-Physical Systems (CPS), big data analytics, robotics, and the Internet of Things (IoT), in order to create automated and interconnected manufacturing systems. The term Industry 4.0 was first introduced in 2011 in Germany, signifying a shift towards integrating information and communication technology (ICT) into industrial production.



Lights-out manufacturing leverages Industry 4.0 technologies to achieve manufacturing automation where manufacturing processes run autonomously with minimal human intervention.



The lights-out manufacturing setup is characterized by two main features:

24/7 Automated Production

Lights-out manufacturing facilities can operate 24/7, autonomously, without the requirements of direct human presence. This concept aims at enhancing efficiency and reducing operational costs by functioning with minimal human operators, thereby eliminating the need for breaks, downtime, or shift changes. This approach also eliminates human-related errors, reduces the risk of worker safety, and improves environmental sustainability, as outlined in the following section.

It is not necessary that the factory operates without any lighting or heating, ventilation, and air conditioning (HVAC); however, factories such as Xiaomi or FANUC do operate a fully 'lights out' setup. Such factories also do not necessarily mean zero human presence. Typically, humans are employed for supervision or for higher, value-added roles, or, more popularly, for collaborating with robots (cobots).

Integration with Advanced Manufacturing Technologies

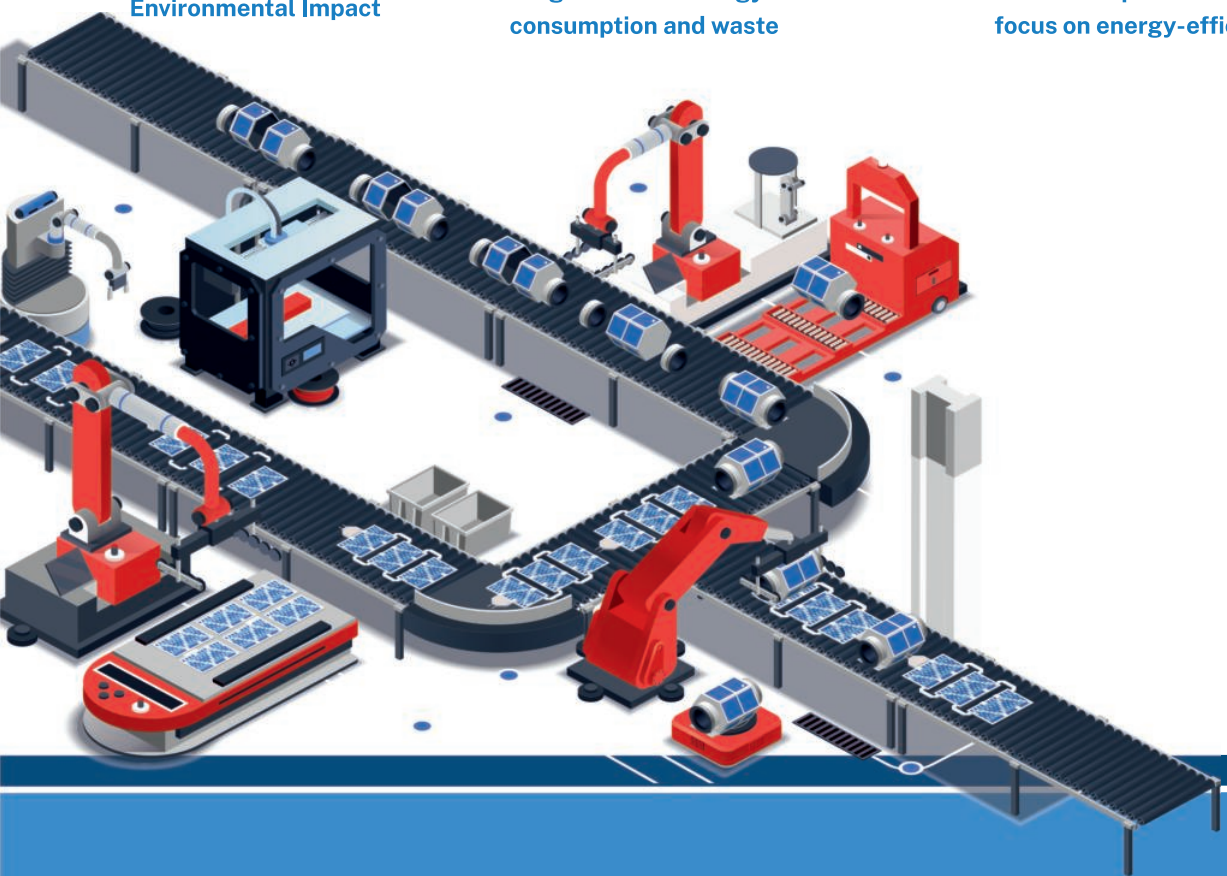
The following key technologies become the foundation for implementing lights-out manufacturing:

- **Robotics and Automation Systems:** The use of robots on assembly lines, for transporting raw material, or for executing precise, repetitive tasks can greatly enhance productivity and improve worker safety. Robotic inspection systems can also be deployed to perform quality checks.
- **Industrial IoT:** At the core of Industry 4.0 is the Industrial Internet of Things (IIoT), which connects machines, smart sensors, and systems to enable real-time data exchange and enhanced decision-making. A network of sensors and devices that enables machine interconnectivity, IoT and manufacturing systems can be connected directly with the ERP software used for production planning. This also includes advanced sensor technologies such as infrared sensors, LiDAR, and machine vision. As of 2025, there are around 19.8 million IoT devices in operation worldwide, according to Statista.
- **AI, Machine Learning, and Data Analytics:** AI and machine learning can create systems that can carry out tasks on the factory floor that usually require human intelligence. For example, a fully autonomous manufacturing environment deploying these technologies can predict failures, suggest decisions, and improve quality control.
- **Digital Twins:** Forming the core technology behind lights-out manufacturing, digital twins allow businesses to create virtual models to optimize performance before deployment.
- **3D or Additive Manufacturing:** 3D printing to create an object layer by layer based on a digital model can be used to create prototypes, custom components, or to replace machine parts without human intervention.
- **Cyber-Physical Systems (CPS):** Integrates manufacturing processes with digital systems to control and optimize production flow. CPS integrated with AR/VR technology can allow personnel to monitor processes remotely.
- **Industrial Cyber-Security:** Protects automated manufacturing systems from cyber threats, for e.g., firewalls or encryption.
- **Cloud Computing and 5G Technology:** High-speed transmission and processing of manufacturing data to enable real-time connectivity between sensors, physical machines, and control systems.

Beyond these key technologies, a lights-out manufacturing setup also employs technologies such as Manufacturing Execution Systems (MES), Distributed Control Systems (DCS), digital threads, model-based systems engineering (MBSE), manufacturing operations management (MOM) application suites, Computerized Maintenance, Management Systems (CMMS) Augmented Reality (AR) and Virtual Reality (VR).

Below is a comparison of the features of traditional vs lights-out manufacturing:

Feature	Traditional Manufacturing	Lights-Out Manufacturing
Human Involvement	High	Minimal to None
Production Hours	Limited by labour shifts	Continuous, 24/7
Error Margin	Higher due to human error	Reduced with automation
Cost Efficiency	Dependent on labour and material costs	Optimized through automation
Workplace Safety	Risks associated with manual labour	Enhanced safety with reduced human presence
Product Customization	Minimal, with focus on mass production	High, with focus on mass customization
Data Utilization	Minimal	Advanced analytics
Connectivity	Minimal	Fully integrated, real-time connectivity
Decision-making	Human-driven	Autonomous, AI-driven
Environmental Impact	Higher due to energy consumption and waste	Lower with optimized energy use and focus on energy-efficient systems



2.2 Key Benefits of Lights Out Manufacturing

The transition to lights-out manufacturing offers several compelling advantages for businesses:

- Reduced Operating Costs:

The transformation to dark factories offers a significant reduction in operating costs by eliminating human labour and associated operational costs. Over time, productivity gains from increased efficiency can be significant, especially in industries that require streamlined, uninterrupted production, such as automotive or electronics. Further, the use of robots can eliminate human errors that lead to rework and the consumption of more materials.

- Increase Productivity:

Advanced robotics and AI-driven systems ensure high precision in the execution of tasks, leading to higher product quality, improved efficiency, and reduced wastage in manufacturing operations.

According to a 2021 report by ResearchAndMarkets.com, the shift to a lights-out manufacturing process can potentially save up to 20% of labour costs and increase productivity output by around 30%.

India's CEAT and Unilever factories joined the World Economic Forum (WEF) network of lighthouse companies in 2025. The WEF stated that these companies observed an average 53% increase in labour productivity and a 26% reduction in conversion costs attributed to technologies such as AI, machine learning, etc.

- Worker Safety:

Automation in manufacturing reduces the risks of workplace accidents caused by handling hazardous materials, heavy machinery, or repetitive motion injuries. In lights-out factories, workers are transitioned into supervisory or technical roles, minimizing their exposure to dangerous environments, which enhances overall workplace safety and employee well-being.

- Resolves Labour Shortages:

As per a 2024 Deloitte survey, nearly 60% of manufacturers cited the inability to attract and retain employees as their top challenge. As per a 2024 Lightcast report, over 4 million older workers have left the global manufacturing workforce since 2020.

A lights-out manufacturing setup resolves issues such as labour shortage or finding and retaining skilled workers by leveraging automation to fill production gaps. This approach enables manufacturers to maintain production levels despite a shrinking workforce.

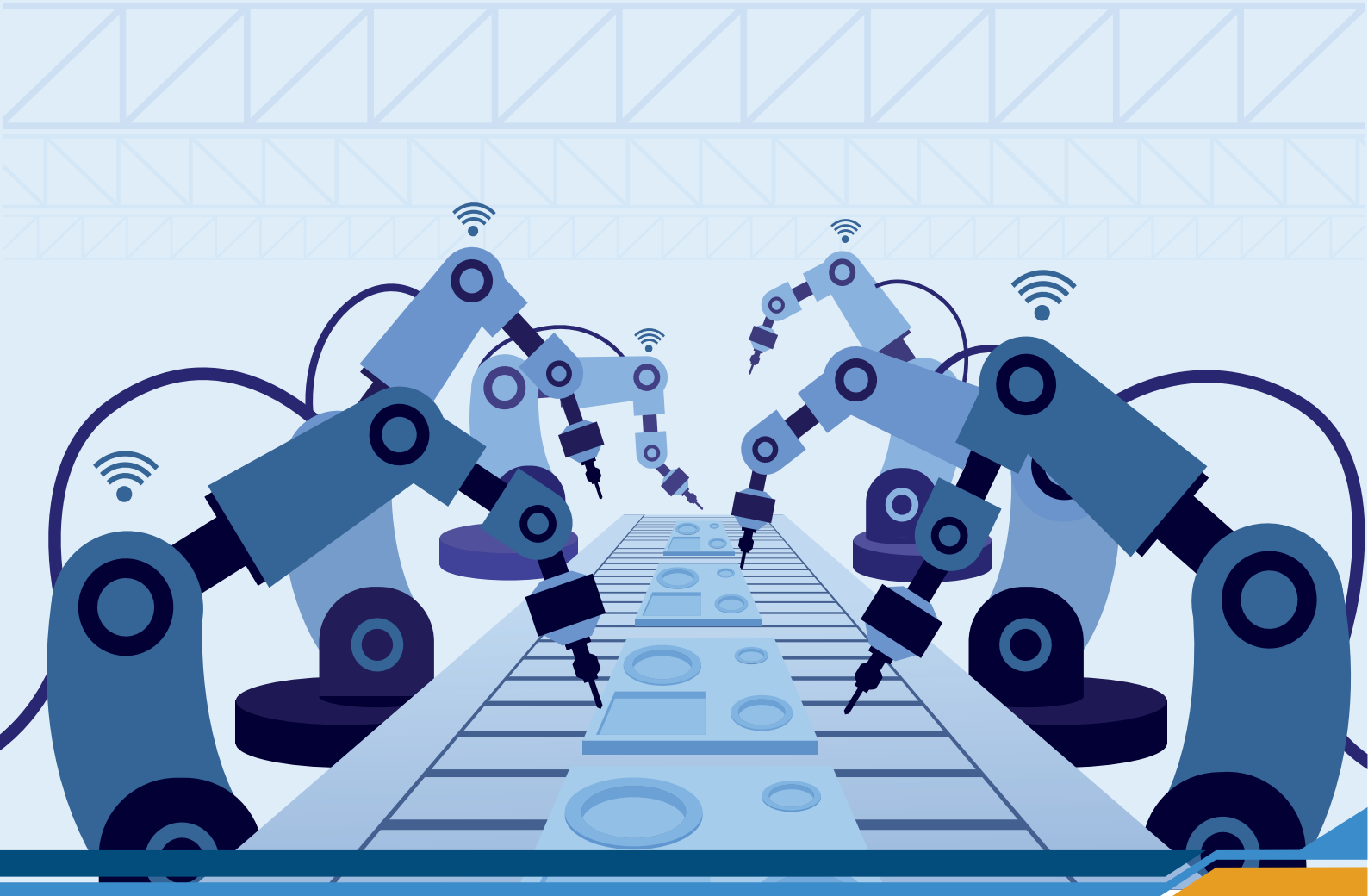
- Improves Environmental Footprint:

Sustainability is one of the most pressing needs in today's business world. With nations and companies around the world pledging to reduce their carbon footprint, manufacturing automation is one of the key steps towards sustainable manufacturing. Fully automated systems reduce the factory's overall energy consumption and carbon emissions associated with human workers, such as commuting and facility maintenance. A lights-out setup can also operate without any lighting or heating, ventilation, and air conditioning (HVAC), which are high-energy-consuming equipment. Implementing smart sensors can monitor energy consumption and reduce waste. Digital twins technology also ensures significant savings in raw material, energy, and resources.

As per a 2024 Bitkom study, annual CO2 emissions in Germany in 2030 can be reduced by roughly 73 million tons if digital transformation is accelerated.

Some key examples of Industry 4.0 technology driving sustainable manufacturing are as follows:

- Tianyang Cement, China, demonstrated that automation at its factory using advanced analytics, autonomous driving, and IoT resulted in reducing carbon emissions by 24%, increasing labour productivity by 105%, reducing unplanned downtime by 56% and improving quality consistency by 25%.
- LG's factory in Changwon, Korea, achieved productivity gains of 17% and reduced energy consumption by 30% by integrating digital twins in its assembly line.
- Schneider Electric's smart factory in Hyderabad, which is one of the World Economic Forum's lighthouse companies as well as a global sustainability lighthouse, was able to reduce its energy consumption by 59%, improve waste optimization by 64%, decrease CO2 emissions by 61%, and reduce water consumption by 57%.



03. LIGHTS-OUT MANUFACTURING: CASE STUDIES

3.1 Lights-Out Manufacturing Case Studies

In this section, we analyse some case studies where lights-out manufacturing has been implemented on a large scale.

FANUC's Lights-Out Manufacturing

In 1982, General Motors announced plans for fully automated plants operated predominantly by robots under the initiative of its CEO, Roger Smith. The initiative was announced under a joint venture with FANUC, a Japanese robotics manufacturer. Although the venture was unsuccessful due to a lack of integration with technology, in 2001, FANUC became the world's pioneer in lights-out manufacturing by operationalizing the first-ever lights-out factory.

At FANUC, robots operate autonomously to produce approximately 50 robots every 24 hours, with the capability to run unsupervised for up to 30 days. FANUC's products are used for setting up fully automated plants all over the world, for e.g., in the US, enabling companies like KAD Models to achieve lights-out manufacturing by integrating FANUC M-710iC/50 and R-1000/100F robots for automated CNC machine tending. Similarly, Athena 3D Manufacturing implemented a FANUC CRX collaborative robot to automate its 3D printing operations.

Tesla's Automation-Driven Production Efficiency

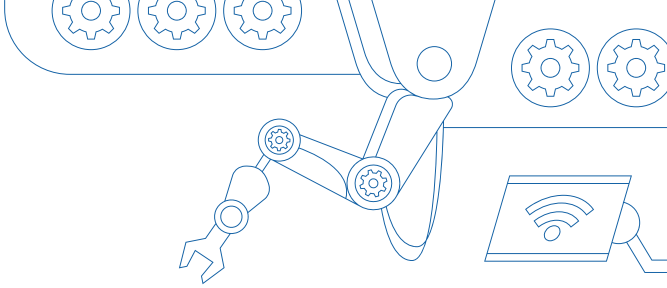
Tesla's Gigafactories are highly automated and vertically integrated, allowing it to develop many components for its vehicles in-house, including batteries and motors.

Tesla's automation success is characterized by the following statistics:

- Tesla's Shanghai Gigafactory is 95% automated, with a 100% automation rate at the welding workshops.
- The Shanghai plant is able to complete a car body every 30 seconds.
- Tesla has reached a global capacity of over 1.9 million vehicles annually.

Tesla has also begun using its humanoid robot Optimus, in low production at its factories, and plans to deploy Optimus for sale by the end of 2025.

In the past, Tesla faced automation issues such as production bottlenecks leading to delays in delivery timelines, cost overruns, and quality control issues. In 2018, Elon Musk admitted that excessive automation at Tesla was a mistake, tweeting that 'humans are underrated'. To address these challenges, Tesla integrated AI in its production systems, transforming them into smart manufacturing hubs. It has also deployed advanced technologies for predictive maintenance, quality control, and AI-powered robotics.



Amazon's Robotic Fulfillment Centers

Amazon automated its warehouse by placing barcode stickers that allow robots to know the precise location of each product. Over 500,000 robotic units were introduced at the warehouse network, which coordinates shipments for delivery. However, Amazon has faced challenges with respect to matching the depth and perception of humans, and Amazon still employs many human workers in its warehouses and uses cobots to improve efficiency.

A 2019 investigation by The Center for Investigative Reporting found higher injury rates at Amazon's robotic fulfillment centers compared to non-robotic facilities, with a serious injury rate reported at 9.6 per 100 full-time workers (as compared to the national warehousing industry average of 4 per 100). In 2023, the Strategic Organizing Center also reported that Amazon's serious injury rate was more than double the industry average. Amazon's March 2024 annual safety report, however, has announced a decline in its warehouse injury rate for 2023.

Lighthouse Companies

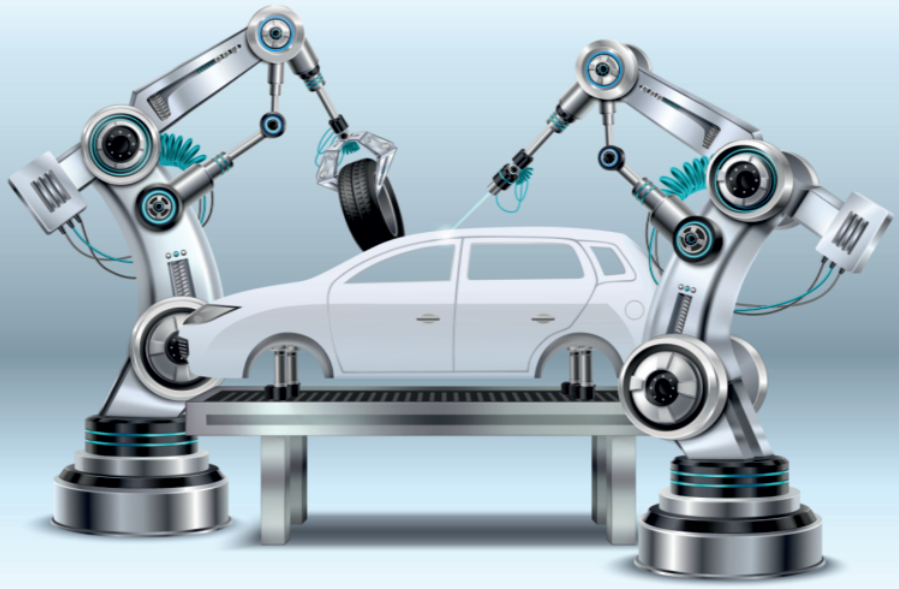
In 2018, the World Economic Forum launched the Global Lighthouse Network with 16 'lighthouse' companies, i.e., companies that implemented advanced 4IR technologies in manufacturing. As of January 2025, there are 189 lighthouse companies in the world, of which 78 are in China, 16 are in India, and 13 are in the US. Lighthouse companies are setting archetypes around the world for best practices and efficient implementation of 4IR technologies in manufacturing.

3.2 Lights-Out Manufacturing: End-Use Cases

The lights-out approach is especially useful for industries such as electronics, automotive, and precision engineering in order to remain competitive in a rapidly evolving global market. Below are some more successful use cases of lights-out, lights-sparse, or automated manufacturing:

Industry	Company	Advanced Manufacturing Technologies and Benefits
Robotics	Hyundai (South Korea)	In Seoul, South Korea, Hyundai Motor Group's DAL-e Delivery robot can autonomously deliver drinks and packages throughout the Factorial Seongsu smart building. Hyundai Motor's Parking Robot can autonomously park vehicles in tight urban spaces, improving the overall interaction with smart buildings.
Electronics	Philips (Netherlands)	At Philips' lights-out factory, 128 robots are used to produce electric razors, with only 9 human quality check workers.
	Xiomi (China)	Xiaomi's newly set up lights out factory can produce 1 smartphone every second, with an annual production capacity of 10 million high-end smartphones as of 2023.
Automation	Siemens (Germany)	At Siemens' Amberg plant in Germany, automation and Industry 4.0 implementation achieved the following results: • 75% of its supply chain is automated and independently handled by machines and robots. • A 99.9% quality standard, producing over 1,000 product variations daily.

Industry	Company	Advanced Manufacturing Technologies and Benefits
Automotive	Bosch (Germany)	• Incorporates digital twins and robotics to connect over 60,000 sensors. • Achieved a 25% increase in production efficiency and reduced inventories by up to 30%.
	Linglong Tire (Serbia)	The USD 900 million European factory set up in 2024 integrates cutting-edge technologies such as artificial intelligence, mobile sensing, industrial big data, and industrial robots to achieve full end-to-end automation.
Semiconductors	TSMC (Taiwan)	Several semiconductor manufacturing companies are investing in 300mm fabs and integrating smart factory technologies to enhance efficiency and productivity. As of 2025, integrated circuit manufacturing for semiconductors involves fully automated 300 mm wafer production with minimal human oversight.
Snacks and Confectionary	Mondelez (Beijing)	Achieved fully automated dough production in biscuits at its Beijing plant.



04. LIGHTS-OUT MANUFACTURING MARKET

A 2021 Gartner study predicted that by 2025, 60% of manufacturers will have more than two completely lights-out processes in at least one of their facilities. While adoption of fully lights-out processes in 2025 is still rare, many companies have made the shift to smart manufacturing and adoption of Industry 4.0 technologies, and a digital transformation is truly underway in the manufacturing sector.

In 2024, technology investments by manufacturing companies accounted for 30% of their operating budget in 2024 (up from 23% in 2023) *Note 1

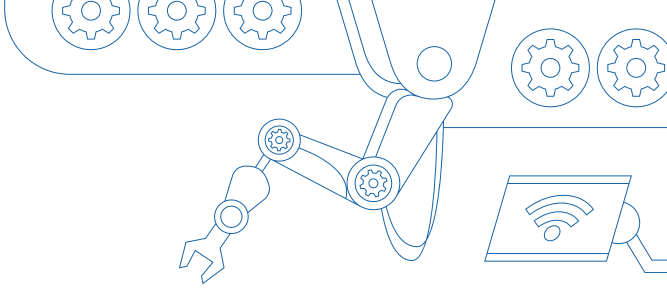
As of 2023, 67% of industrial manufacturing companies have initiated a transition to smart manufacturing. *Note 2

Investment in advanced technologies increased by 30% YoY from 2023 to 2024. Top 3 technologies with the highest ROI include cloud, generative AI, and 5G. *Note 2

Notes:
1. Source: 2024 State of Smart Manufacturing Report by Rockwell Automation
2. Source: Statista

In the pre-COVID era, there was already widespread excitement about Industry 4.0 in the manufacturing sector. Post pandemic, the business world quickly realised the urgent need to adopt smart manufacturing processes. During the lockdowns, as many factories had to shut down due to workers' unavailability and social distancing regulations, facilities with lights-out capabilities were able to maintain production levels during the lockdowns, unlike traditional factories. According to the World Economic Forum, "2020 was the year that automation started taking over the workforce". Companies like Hitachi, Mitutoyo, and Omron have acknowledged that the COVID-19 pandemic was a motivation for their investments and M&A initiatives in automation since 2020. The pandemic proved two things: one, that most manufacturing tasks, once automated, only require access to data and not machinery, and two, that dependence on imports from another country for production includes many risks.

In this section, we discuss the global lights-out manufacturing market as well as interrelated markets such as smart manufacturing, industrial robotics and automation, and AI in manufacturing.



4.1 Analysis of the Global Smart Manufacturing Market

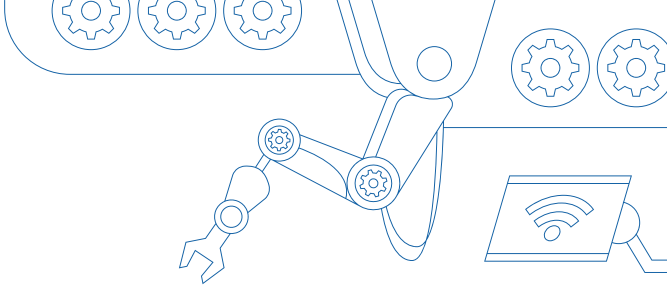
Market Type	Market Size	CAGR	Key Statistics
Global Lights-out Manufacturing ** source: markets.us*	USD 47.3 billion to USD 94.8 billion (between 2024 and 2034)	7.2%	The automotive segment, which includes EVs, accounted for a 40.8% market share in 2024 in the lights-out manufacturing market.
Smart Manufacturing ** source: Fortune Business Insights*	USD 394.35 billion to USD 998.99 billion (between 2024 and 2032)	14.2%	The electronics sector takes the second-highest share (20%) in global automation, followed by semiconductors, pharmaceuticals, and industrial manufacturing segments.
AI in Manufacturing ** source: Global Market Insights*	USD 4.2 billion to USD 60.7 billion (between 2024 and 2034)	31.2%	According to Deloitte's 2024 Future of the Digital Customer Experience survey, 55% of surveyed industrial product manufacturers are already leveraging gen AI tools in their operations, and over 40% plan to increase investment in AI and machine learning over the next 3 years.
Industrial Automation ** source: Persistence Market Research*	USD 165.1 billion to USD 307.7 billion (between 2023 and 2030)	9.3%	According to a Virtue Market Research: • In 2023, almost 40% of global factories adopted digital twins technology to optimize productionprocesses. •75% of automotive manufacturing plants utilized robotic process automation (RPA) in 2023. The number of automated guided vehicles (AGVs) in operation in manufacturing plants surpassed 200,000 units worldwide in 2023.
Industrial Robotics ** source: Astute Analytica*	USD 26.99 billion to USD 235.28 billion (between 2024 and 2033)	27.2%	The industrial robotics segment dominates in the adoption of smart technologies with a 45.2% share (covered in detail below).
Smart Warehouse ** source: Dimension Market Research*	USD 21.9 billion to USD 77.8 billion (between 2024 and 2032)	15.1%	----
Internet of Things (IoT) ** source: : US Department of Commerce*	USD 1.1 trillion by 2026	----	The number of IoT devices worldwide is forecast to more than double from 19.8 billion in 2025 to more than 40.6 billion IoT devices by 2034, according to Statista.

4.2 Industrial Robotics Boom

In 2024, the global market value of industrial robot installations reached an all-time high of USD 16.5 billion, according to the International Federation of Robotics (IFR), with almost 4.3 million units in operation in factories worldwide as of September 2024 (up by 10% as compared to 2023).

Below are some key statistics and trends with regards to industrial robot installments in the top 5 countries as compared to India:

Robot Density (per 10,000 employees as of 2023	Annual Installations in 2023 (in units)	Key Geographical Trends
295	37,587 (down 5% YoY)	Third-largest industrial robotics market globally with respect to annual installations. The US ranked 10th in the world in 2023 among the most automated countries in the manufacturing industry, with a robot density of 295 units.
419	46,106 (down 9% YoY)	The world's second-largest industrial robotics market, delivering 38% of the global robot supply in 2023. The world's second-largest market for industrial robots in terms of annual installations.
470	276,288 (down 5% YoY)	World's largest robotics market, representing 51% of global demand. The local supply of annual industrial robot installations in China increased from 30% in 2020 to 47% in 2023. In 2023, nearly two-thirds of industrial robots in the electronics industry were installed in China alone, of which 54% were supplied by Chinese manufacturers.
429	28,355 (up 7% YoY)	Europe's largest industrial robotics market, and fifth-largest in the world in terms of annual installations. The automotive sector accounts for 32% of all robotic installations.
1,012	31.444 (down 1% YoY)	Fourth-largest robotics market in the world in terms of annual installations. Ranks 1st in terms of robot density since 2021.
148 (as of 2021)	8,510 (up 59% YoY)	India is the 7th largest market with respect to annual robot installations. India's operational stock of industrial robots has nearly doubled since 2018, reaching 44,958 units in 2023, with an average annual growth rate of 14%.



Some more key trends with respect to the industrial robots market are as follows:

- The annual installations of industrial robots worldwide exceeded 500,000 units in 2023 for the third consecutive year.
- 70% of all newly deployed robots in 2023 were installed in Asia, 17% in Europe and 10% in the Americas.
- The automotive sector accounted for around 25.40% of total industrial robot installations in 2024, with over 70% of such units used for BIW framing, spot-welding, and paint lines.
- According to Forbes, 32% of current production lines are managed by both robots and cobot technology. In 2023, cobots made up 10.5% of industrial robot installations globally.
- The key suppliers of industrial robots, namely, FANUC, ABB, Yaskawa, KUKA, and Mitsubishi Electric, control about 57% of global shipments of industrial robots, according to Astute Analytica, a market research firm.
- Automotive OEMs reflect the majority demand for industrial robots, with the fastest incremental growth delivered by battery, semiconductor, logistics, and pharmaceuticals plants.

4.3 Key Markets

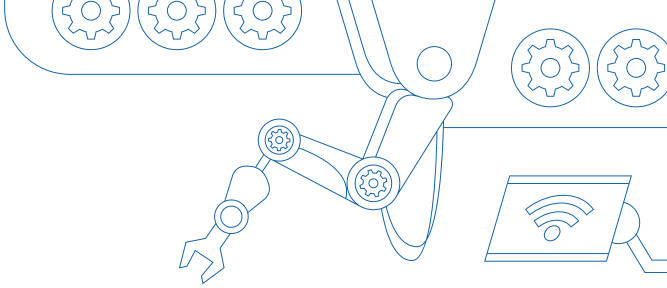
China

China is a global manufacturing powerhouse. The United Nations Industrial Development Organization (UNIDO) projected in 2024 that China will account for approximately 45% of global manufacturing by 2030, with the US's share falling to 11%. For comparison, in 2000, the US, together with its allies in Asia, Europe, and Latin America, accounted for the overwhelming majority of global industrial production, with China contributing only 6%.

According to the Ministry of Industry and Information Technology (MIIT), China has established more than 30,000 basic-level smart factories, as well as 1,200 advanced-level and 230 excellence-level smart factories. MIIT also reported that on average, product development cycles have been reduced by 28.4%, production efficiency has increased by 22.3%, defect rates have dropped by 50.2%, and carbon emissions have decreased by 20.4%.

China's Made in China 2025 plan, announced in 2015, emphasized smart manufacturing as an important facet to modernise the Chinese manufacturing sector through AI, robotics, and smart technologies. Eight government departments are involved in China's smart manufacturing industrial development, and have issued many guidelines and initiatives to meet their goals. In 2022, the government announced its Robot+ initiative, setting goals for over 200 robotic applications and over 100 innovative technologies by 2025. In 2023, China installed 276,288 industrial robot units, representing 51% of global demand.

Chinese manufacturing factories are rapidly making the transition towards the smart manufacturing market. For example, in 2016, Foxconn replaced 60,000 workers with robots in its factory in Kunshan and automated 30% of its operations. Further, BYD, a leading EV manufacturer, uses robots to assemble EV batteries and chassis in its factories. A major driving factor for this transformation could be the fact that China's working-age population may decline by two-thirds by the end of the century, and the industrial sector needs to rapidly transform to mitigate the effects of a possible labour shortage.



Japan

The Asia-Pacific region is expected to dominate the lights-out manufacturing market with a 44% share in 2025, according to Coherent Market Insights, a market research firm. Asia-Pacific held a 39.5% share of the global factory automation market in 2024, according to Grand View Research. This market share is predominantly through the accelerated growth in smart manufacturing from countries such as China, Japan, India, and South Korea.

Japan is one of the pioneers of lights-out manufacturing and advanced manufacturing technologies. FANUC, a Japanese company, has been operating a fully lights-out production setup since 2001. Japan is also the world's leading supplier of industrial robots, as noted in the above section. Japanese manufacturers such as Toyota and Honda are increasingly integrating AI-driven automation and robotics in their manufacturing processes. Japan is also making significant advancements in decentralized IoT platforms.

Japan's Ministry of Economy, Trade and Industry (METI) launched the Connected Industries initiative in 2017 to promote the adoption of IoT, cloud computing, AI, and other advanced technologies in manufacturing as part of its Industry 4.0 strategy. The policy, aligned with Japan's Society 5.0 vision, provides subsidies and tax incentives to support companies investing in smart manufacturing and encourages cross-industry collaboration and public-private partnerships. The initiative is distinct from Germany's Industry 4.0, with METI explaining that the initiative leverages Japan's strengths to connect manufacturing with sectors such as healthcare and agriculture. The framework also includes IoT standardization to support SMEs and global supply chains.

US

In 2024, North America accounted for 27% of the smart manufacturing market, according to Grand View Research, with the US accounting for over 80% share of the global factory automation market. North America represented 35% of the global industrial automation market in 2023. There are many smart manufacturing factories in the US, including Tesla's Gigafactories, Ericsson's 5G smart factory, and Ford's EV center.

The US government has provided many initiatives to push advanced manufacturing technologies and to strengthen domestic manufacturing capabilities. The most recent initiatives are as follows:

- In 2024, the US Department of Energy's Advanced Materials and Manufacturing Technologies Office announced a USD 33 million funding opportunity to drive the advancement of smart manufacturing technologies and processes and aid in the clean energy transition.
- In November 2024, the Clean Energy Smart Manufacturing Innovation Institute (CESMII) partnered with the National Institute of Standards and Technology's Manufacturing Extension Partnership (NIST MEP) to support small and medium-sized manufacturers (SMEs) by providing them with access to advanced technologies, training, and resources. CESMII has developed over 50 smart manufacturing courses, training over 6,000 workers annually.
- In January 2025, the US Department of Energy announced USD 13 million in funding with the aim of expanding access to smart manufacturing technologies and high-performance computing (HPC) resources for domestic manufacturing firms.

Germany

As the pioneer of Industry 4.0, Germany is a global leader in automation and smart industrial manufacturing. In 2023, the US International Trade Administration reported that by 2025, 84%of German manufacturers plan to invest approximately USD 10.5 billion annually in smart manufacturing, with 75% of German companies in most industries already having implemented digital solutions.

Germany's automotive sector accounts for the majority (32%) of all robotic installations, with major players including BMW, Mercedes-Benz, and Audi for welding, assembly, and EV production.

KUKA, a global automation company based in Germany, offers solutions for manufacturers that enable the setting up of lights-out or smart manufacturing and the adoption of advanced digital technologies.

Germany is also leading in respect of additive manufacturing and advanced materials. According to a study by the European Patent Office, 50% of all additive manufacturing patents registered in Europe originate in Germany.

South Korea

South Korea has established itself as a global leader in industrial automation, especially in industrial robotics adoption. South Korea is the world's largest industrial robotics market and the fourth largest robot market in the world in terms of annual installations, following the US, Japan, and China. The newly opened Seoul Robot & AI Museum (RAIM) showcases to the public its advanced robots and technologies, such as automated and wearable robots.

South Korea's technological prowess is supported by various government initiatives, such as the 2014 Manufacturing Innovation 3.0 Strategy and the government's vision in 2022 to establish 30,000 fully automated manufacturing firms by 2025. In 2022, the Korean government injected USD 1.9 billion into R&D projects to incentivize SME companies to advance and upscale automated technologies. The government has also committed to training around 40,000 skilled workers to manage fully automated manufacturing sites.

South Korea's automation growth is driven by its semiconductor, electronics, and automotive sectors. Korea's Human-Machine Interface (HMI) segment is also demonstrating remarkable growth potential, with an expected growth rate of approximately 10% from 2024 to 2029 according to Mordor Intelligence, a market research firm. This growth is primarily driven by the increasing demand for advanced visualization and control interfaces in manufacturing facilities, enabling the implementation of cloud-enabled HMI platforms.

05. SMART MANUFACTURING IN INDIA

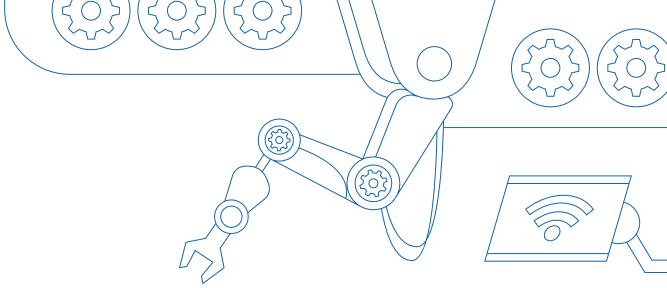
Adoption of fully lights-out manufacturing in India is still low. A 2023 PwC survey found that only 8% of Indian companies across the six surveyed sectors have achieved a complete digital transformation. However, many manufacturers in India are rapidly adopting Industry 4.0 technologies and beginning the transition to smart manufacturing. The AI and analytics technology has seen an implementation rate of 54% among Indian companies according to the PwC survey. These companies are using technologies such as machine sensors, cloud technology, robotics, and automation to improve production output and increase efficiency.

A 2022 NASSCOM report on India's Industry 4.0 Adoption predicted that two-thirds of Indian manufacturers will embrace digital transformation by 2025. The report also expected that digital technologies will account for 40% of total manufacturing expenditure by 2025 as compared to 20% of expenditure in 2021.
In this section, we examine the current state of India's manufacturing sector, the market size, key players, and the key emerging trends in India's digital transformation.

5.1 Analysis of India's Manufacturing Sector

Snapshot of India's Manufacturing Sector

Manufacturing Potential	Third most sought-after manufacturing destination in the world, with the potential to reach USD 1 trillion by FY 2026.
Contribution to GDP	India's manufacturing sector has consistently contributed 16% to 17% of the country's GDP. As of 2025, the sector's contribution to India's GDP is around 13% to 14% (in comparison, the contribution to GDP of manufacturing sectors in other countries is 29% (China) or 20% (Japan and Germany)).
Employment	The sector employs over 27 million workers.
Share in Global Manufacturing Market	According to the Economic Survey 2024-25, India has a 2.8% share in global manufacturing. In comparison, China's share is 28.8%, and is projected to increase to 45% by 2030. The survey also predicts that India's industrial sector is estimated to grow by 6.2% in the fiscal year 2025.
Opportunities	Manufacturing production in India increased by 5.7% year-over-year in May 2023, exceeding market estimates of 1.8%.
Policy Support	Government initiatives such as Make in India, Digital India, and the Production Linked Incentive (PLI) scheme (discussed in detail below) have provided a growth boost to sectors such as electronics, pharmaceuticals, and automotive, attracting Foreign direct investment (FDI) and focusing on enhancing domestic manufacturing capabilities.
Foreign Investment	FDI inflows into India's manufacturing sector rose by 69% in 2024, reaching USD 165.1 billion.
Competition	Indian MSMEs face stiff competition from MSMEs in other developing economies, such as China, most notably in electrical and electronics goods, as well as metallurgical/chemical engineering products. The Indian manufacturing sector is also facing stiff competition from developing economies with lower labour costs, such as Vietnam, whereas the higher cost markets are rapidly advancing with the use of cutting-edge technologies and adopting automation in manufacturing, which cuts personnel costs and increases operational efficiency.



Key Manufacturing Sectors

India's manufacturing sector is primarily driven by pharmaceuticals, motor vehicles, and cement, with the automotive sector also registering high growth. 90% of India's manufacturing companies are small and medium-sized enterprises (MSMEs), contributing around 45% to 50% of exports.

Electronics Manufacturing	In 2024, on the 10th anniversary of the 'Make in India' initiative, Union Commerce and Industry Minister Mr. Piyush Goyal reported that India has achieved an 85% reduction in mobile phone imports, with a 200% increase in manufacturing jobs from 2022 to 2024. The Indian Cellular and Electronics Association (ICEA) reported that India's electronics sector has transitioned from being 78% import-dependent in 2014 to 97% of mobile phones in India now being produced domestically. India has committed to reaching USD 300 billion worth of electronics manufacturing and exports of USD 120 billion by 2025-26, and is expected to contribute 20% of the global production of smartphones by 2032.
Automotive	India is currently the world's fourth-largest automotive market. Demand for industrial robots from the automotive industry reached 3,551 units in 2023, reflecting an increase of 139% as compared to 2022.
Telecom	The total number of cellular IoT connections reached 53.7 million in July 2024, showing a 34% year-on-year growth, according to Counterpoint Research (for comparison, China has 2.3 billion cellular IoT connections, accounting for a 70% worldwide share).
FMCG	At L'Oréal India's Pune plant, the deployment of cobots to automate the industrial processes achieved a 5% increase in Overall Equipment Effectiveness (OEE).
Semiconductors	• India, which has traditionally been a hub for semiconductor research and development, is poised to launch its 'Made in India' chip in 2025. • India has the potential to capture 10% of the global semiconductor market by 2030 (currently less than 1%), according to Ashok Chandak, President of the India Electronics and Semiconductor Association (IESA). • Tata Electronics and PSMC are building India's inaugural AI-enabled greenfield semiconductor fabrication plant, targeting demand in AI, automotive, computing, data storage, and wireless communication markets.
Agriculture	• The AI4AI initiative, launched by the World Economic Forum in partnership with India's Agriculture Ministry and Telangana state, transformed chilli farming whereby over 18 months, 7,000 farmers doubled their incomes to USD 800 per acre, improved yields by 21%, and reduced pesticide and fertiliser use by 9% and 5%, respectively. • In Tamil Nadu, the government is collaborating with institutions like Anna University to deploy drones for crop monitoring and pesticide spraying.
Textile	The sector contributes 2.3% to India's GDP, and is increasingly leveraging solutions such as Computer Aided Design and Manufacturing (CAD/CAM) in optimising processes such as fabric cutting, stitching, and quality inspection.

- COVID-19 and “China Plus One”

In the backdrop of the COVID-19 pandemic and rising US-China trade tensions, companies are looking for alternatives for their supply chain. India is attempting to cash in on this opportunity by making its manufacturing sector technologically advanced and robust. India offers some compelling advantages for manufacturing companies seeking to enter the Indian market, including its large population base, low labour cost, and large workforce with skilled engineers.

The ‘China Plus One’ business strategy has led major electronics firms such as Apple, Samsung, and Foxconn, to establish manufacturing facilities in India. India’s target of achieving a USD 7 trillion GDP by 2030 will be primarily driven by growth in the digital sector and an increase in electronics manufacturing, led by the production of mobile phones. At the same time, the Economic Survey 2023-34 acknowledged that India will not automatically take over the manufacturing space vacated by China, and that India may need to facilitate more Chinese investments in the country to make the most of the global phenomenon.

5.2 India’s Smart Manufacturing Market

Indian manufacturers are investing around 35% of their operating budgets in technology implementation, as compared to the global average of around 23%.

The market size of India’s industrial automation market is estimated to grow from USD 17.28 billion in 2025 to USD 33.64 billion by 2030, reflecting a Compounded Annual Growth Rate (CAGR) of 14.26%, according to Mordor Intelligence, a market research firm. Of this, the majority share (70%) of the industrial automation market is dominated by factory automation solutions such as industrial control systems, field devices, and manufacturing execution systems.

India’s industrial robots market size is estimated to grow from USD 522.12 million in 2025 to USD 733.91 million by 2033, reflecting a CAGR of 9.6%, according to Straits Research. According to Techarc, all of the 22 automobile OEMs in India have centred their core strategies around connected cars. In 2025, the majority of passenger cars launched in India will offer 5G IoT connectivity, onboard GenAI, and cloud connectivity.

5.3 Key Players in India's Smart Manufacturing Market

India's manufacturing sector has witnessed major new investments in production facilities by leading companies. The key players leading in smart manufacturing and Industry 4.0 technology implementation are outlined below.

COMPANY	AUTOMATED MANUFACTURING
Unilever	• Unilever's Beauty & Wellbeing factory in Tinsukia, India, is a great example of a fully lights-out, end-to-end value chain production facility, achieving an 86% reduction in product defects. • The company implemented over 50 digital use cases, which helped reduce planning frozen periods from 14 days to one, and cut the time for sustainable packaging trials by 84%. • The company uses sustainably sourced biofuels, combined with a boiler digital twin, which has reduced the factory's Scope 1 greenhouse gas emissions by 88%, while also providing local farmers with a profitable use for their agricultural waste. • The factory was recognized by the World Economic Forum as a global lighthouse in 2025.
Schneider Electric	7 of Schneider Electric's factories have joined the World Economic Forum's Global Lighthouse Network, of which three, including the Hyderabad factory, are global Sustainability Lighthouses. Schneider Electric's Hyderabad smart factory, over four years, has achieved: • Reduced energy consumption by 59%. • Improved waste optimization by 64%. • Reduced CO2 emissions by 61%. • Reduced water consumption by 57% • Reduced energy costs by between 10% and 30%. • Reduced maintenance costs between 30% and 50%.
Tata Steel	• The first company in India to be recognized as a lighthouse company. • Two out of three of its lighthouse facilities are in India, of which one is a greenfield facility in Kalinganagar, and the other is the brownfield facility in Jamshedpur. • The company achieved improved time-to-market by 50% after implementing digital and analytics solutions in 2017.
Siemens	• The Siemens plant in Kalwa, Mumbai, a brownfield factory operating for over 50 years, demonstrated the success of digitalisation when it was able to reduce its product cycle time by over 50%, from 21 seconds to 9 seconds, despite the increase in quality checks by over 200% from 22 to 68. • The factory employed digital twins, cloud, IoT, and data analytics. • Although the Kalwa plant is only a small division in India, representing only 16% of Siemens' worldwide profits, its brownfield digital transformation success is noteworthy.
Mahindra & Mahindra (India)	Mahindra & Mahindra, at its Chakan plant, employs significant mechanization in its automotive manufacturing plants, including automated robots and conveyors, Computer-Aided Manufacturing (CAM), and automated storage and retrieval systems (AS/RS). The Chakan facility, with a focus on sustainability, uses a fully automated engine assembly plant with temperature and humidity control, an Online Cold Testing Facility, and a dust-proof environment.

5.4 Initiatives by the Indian Government

The Indian government has launched several initiatives to boost manufacturing, promote digital transformation, and accelerate the adoption of Industry 4.0 technologies within its manufacturing sector. These schemes aim to position India as a global manufacturing hub and enhance its competitiveness. The Atmanirbhar Bharat initiative, launched in May 2020, promotes self-reliance through domestic manufacturing and technology development. Through the introduction of different programmes and policies such as Make in India, the Production-Linked Incentive (PLI) scheme, and others, the Indian government set a target to increase the manufacturing sector's contribution to GDP to 25% by 2025.

- Make in India

The Make in India initiative, launched on September 25, 2014, has helped boost the FDI equity inflow in the manufacturing sector by 57% between 2014 and 2022 compared to the previous eight years (2006-2014). The scheme focuses on 27 key sectors, including electronics, automobiles, and defence, with an emphasis on ease of doing business, infrastructure development, and skill enhancement.

- Digital India

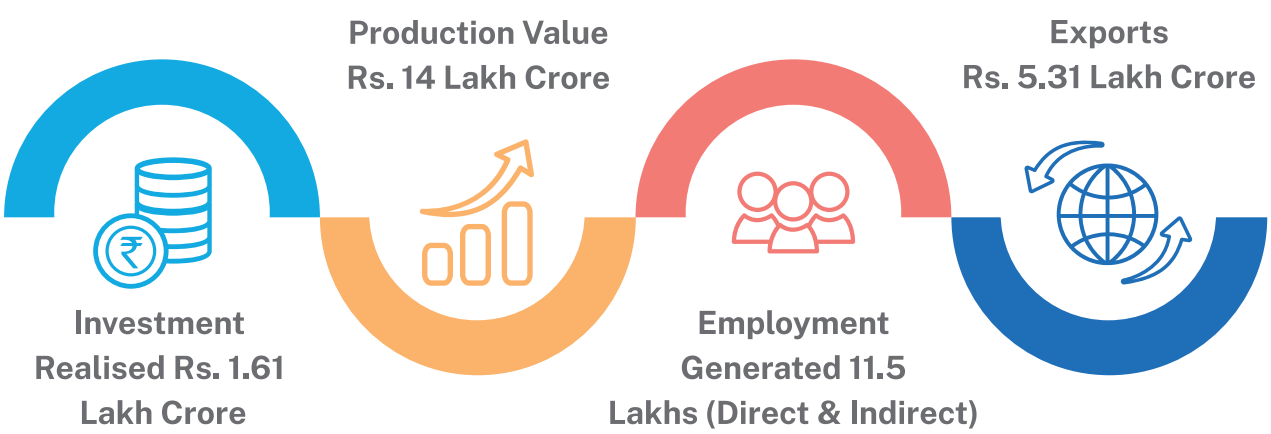
The Digital India scheme launched in 2015 aims to transform India into a digitally empowered society and knowledge economy. It focuses on three key areas, namely, digital infrastructure, governance, and services on demand, and digital empowerment of citizens. The initiative supports smart manufacturing by enhancing digital infrastructure and promoting technologies like AI, IoT, and cloud computing. According to the 2024 report, State of India's Digital Economy by the Indian Council for Research on International Economic Relations (ICRIER), India is the third largest digitalised country in the world, behind the US and China; however, India ranks 12th among the G20 countries in terms of the level of digitalisation of the user.

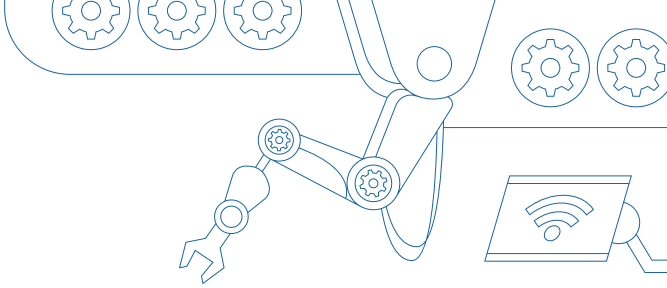
- Production-Linked Incentive (PLI)

The Production-Linked Incentive (PLI) scheme, launched in 2020 by the Ministry of Electronics and Information Technology (MeitY), offers financial incentives to companies for enhancing domestic manufacturing and reducing import dependence. Focusing on 14 sectors, including electronics and smartphones, semiconductors, automobiles, medical devices, and pharmaceuticals, the scheme aims to develop a smart manufacturing ecosystem in India.

As per a March 2025 PIB release, 764 applications have been approved under PLI Schemes, including 176 MSMEs. The release also acknowledges growth in the drone sector, with turnover increasing seven-fold under the PLI scheme for drones and drone components, with the majority of growth driven by MSMEs and startups. Under the PLI scheme, India's electronics manufacturing sector has transformed from a net importer to a net exporter of mobile phones.

PLI Scheme: Key Achievements
as of November 2024





SAMARTH Udyog Bharat 4.0

The Ministry for Heavy Industries and Public Enterprises launched the SAMARTH Udyog Bharat 4.0 initiative, which stands for Smart Advanced Manufacturing and Rapid Transformation Hub. SAMARTH is aimed at promoting the adoption of Industry 4.0 technologies among MSMEs. The initiative aims to create a national ecosystem for smart manufacturing, attract foreign investment in advanced manufacturing technologies, and foster collaboration and entrepreneurship within Industry 4.0 manufacturing.

Under the initiative, 4 SAMARTH centres have been set up in Pune, Delhi, and Bengaluru. Further, 10 cluster Industry 4.0 experience centres have been approved to be established across India by the Centre for Industry 4.0 (C4i4) Lab, Pune. The C4i4 Lab, Pune, has conducted Digital Maturity Assessments for three companies in Karnataka, providing them with tailored Industry 4.0 transformation roadmaps. Smart Manufacturing Demo & Development Cell, CMTI, Bengaluru has transferred technologies, provided training, and collaborated with various industries/MSMEs in Karnataka.

Skill India

Skill India, launched in 2015, is a government initiative aimed at developing a skilled workforce to meet industry demands by providing industry-relevant vocational training and establishing National Skill Development Centers (NSDCs). For the manufacturing sector, upskilling involves training in precision engineering, automation and robotics, advanced welding and machining, and electronics and electrical engineering. While the adoption of automation and AI may lead to some job displacement, these initiatives also expect the creation of new job opportunities in emerging sectors such as robotics, data analysis, and AI, so that workers can transition into these roles after reskilling and training.

Other Initiatives

The government has also launched many other schemes and programmes, including:

- The **India AI Mission,** approved in March 2024, aims to develop AI-based solutions and ensure the responsible and transformational use of AI across various sectors, including manufacturing.
- The **National Mission on Interdisciplinary Cyber-Physical Systems**, approved in 2018, emphasises the integration of AI in manufacturing processes through smart factories to enhance efficiency and innovation.
- The **Digital MSME Scheme**, launched in 2017, aims to digitally empower MSMEs by incentivizing the adoption of Information and Communication Technology (ICT) tools in production and business processes.
- The **FutureSkills PRIME** initiative was launched in 2020 to train 1.4 million workers in technologies such as AI, IoT, and cloud computing, with 1.2 million professionals trained by 2024. Bosch India collaborates with FutureSkills under this initiative for robotics training.
- **Labour reforms:** In 2020, the government consolidated 29 labour laws, which were historically complex and outdated, into four Labour Codes to simplify and modernize labour laws. These codes aim to simplify compliance, enhance worker welfare, and promote ease of doing business.
- **Data privacy laws:** India's primary data privacy law is the Digital Personal Data Protection (DPDP) Act, 2023, which regulates the processing of personal data in digital environments. The act addresses privacy concerns critical for Industry 4.0 technologies, which use data for AI, IoT, and analytics. In January 2025, the Ministry of Electronics and Information Technology (MeitY) released the draft Digital Personal Data Protection Rules, 2025.
- **Other reforms:** In 2013, the government reformed land acquisition regulations. Also, many tax simplifications are provided under the Goods and Services Tax (GST).

06. RISKS AND CHALLENGES

6.1 Challenges to Lights-Out Implementation

Lights-out manufacturing, or “dark factories,” represents the pinnacle of automation, operating with minimal or no human intervention, enabling 24/7 production with reduced labour costs. However, the transition to these advanced manufacturing systems is not easy. According to the State of Smart Manufacturing Report published by Rockwell Automation, the primary obstacles to growth in the area of smart manufacturing are inflationary pressures, rising energy prices, cybersecurity concerns, and ongoing skills shortages. Further, production bottlenecks in areas such as sensing, connectivity issues, and a lack of uniform standards for automation in manufacturing are also obstacles to a smooth digital transformation.

In this section, we examine the risks, challenges, and obstacles to the transition to a fully automated manufacturing industry, with a special focus on India’s manufacturing sector.

High Initial Investment and ROI Concerns

Adopting advanced manufacturing technologies such as IoT sensors, artificial intelligence, and robotic automation requires a very high investment. On average, small-scale warehouse automation costs range between USD 50,000 and USD 500,000, according to Vecna Robotics. A huge capital outlay is necessary for purchasing cutting-edge equipment or for upgrading the existing technological setup. The transition also demands retraining or upskilling the workforce to operate the new technology. Additionally, determining the return on investment (ROI) for smart manufacturing initiatives can be uncertain, since the transition to smart manufacturing requires complex and costly integration with existing systems, extended deployment time, and a specialized workforce.

The high initial capital requirement, coupled with an uncertain ROI, can be restrictive for many companies wanting to embrace advanced manufacturing technologies, especially small and medium-sized enterprises (SMEs). This is especially true in the case of India, where 90% of all manufacturing companies are small and medium-sized companies (MSMEs), but most of which are still using outdated technology and systems. At the same time, a lack of technological adoption is one of the critical barriers impeding the growth of MSMEs in India.

Skill Gaps and Workforce Transition Challenges

As per a 2024 Deloitte survey, nearly 60% of manufacturers surveyed cited the inability to attract and retain employees as their top challenge. As per a 2024 Lightcast report, over 4 million older workers have left the global manufacturing workforce since 2020.

The transition to a lights-out manufacturing setup resolves issues such as labour shortage or finding and retaining skilled workers by leveraging automation to fill production gaps. This approach enables manufacturers to maintain production levels despite a shrinking workforce. According to the World Economic Forum’s 2025 jobs report, about 40% of the core skills in the manufacturing and supply chain sectors will change in the next 3-5 years, and, as a result, more than 54% of incumbent workers will need additional training by 2030.

A 2024 study conducted by Deloitte and The Manufacturing Institute showed that 1.9 million manufacturing jobs could go unfilled over the next 10 years if talent challenges are not addressed.

Technological Challenges

Although the transition to a smart manufacturing setup reduces the risks to worker safety by employing automated processes and robotic automation, there can still be safety risks in case human intervention is required to prevent hazards. This means that any transition to an automated setup must be accompanied by other advanced technologies such as smart sensors, AR/VR simulations, AI-powered analytics, and real-time predictive maintenance.

To establish a fully lights-out factory, several components and technologies must be implemented, such as automated guided vehicles (AGVs), CNC machine tools and robots, automation for each production process, conveyors, sensors, sophisticated vision systems, a comprehensive digital infrastructure, and real-time control software, with all these technologies and machines interconnecting to form a seamless system. Further, lights-out systems are best suited for automating repetitive tasks, but may pose challenges for automating dynamic or customized production.

When Tesla faced automation issues, such as production bottlenecks leading to delays in delivery timelines, cost overruns, and quality control issues, Elon Musk, in 2018, famously admitted that excessive automation at Tesla was a mistake, tweeting that 'humans are underrated'. With such challenges in mind, many factories may choose a lights-sparse approach instead of a fully lights-out setup.

Supply Chain and Infrastructure Limitations

The success of a lights-out manufacturing depends on an end-to-end digitized supply chain. Presently, most manufacturers operate within fragmented and outdated supply networks that lack digital integration. This is especially true in India, where manufacturing facilities are operating with poor infrastructure, inadequate logistics support, poor last-mile connectivity, outdated warehousing systems, a lack of technology awareness, and regulatory hurdles. Upgrading the supply chain to integrate digital technologies is a resource-intensive exercise and is one of the major barriers to smart manufacturing adoption.

Cybersecurity Risks

The manufacturing sector has become an increasingly attractive target for cyberattacks due to its reliance on interconnected systems and automation. There is also an increase in cyber threats targeting industrial control systems (ICS) and operational technology (OT), with the US Cybersecurity and Infrastructure Security Agency (CISA) warning that ransomware and nation-state attacks increasingly target critical manufacturing sectors.

According to a 2024 IBM report, the global average cost of a data breach reached USD 4.88 million, the highest to date, and showed a 10% increase as compared to 2022.

Increased automation raises cybersecurity threats, including hacking and data breaches. Companies transitioning to smart manufacturing must also establish strong security and encryption protocols, including continuous monitoring, network segmentation, and employee training.

Regulatory Hurdles

Another major challenge is the lack of uniform standards for automation in the manufacturing industry. Although many countries have their own set of regulations and standards regarding labour laws, safety certifications, and data protection, there is no consensus on a set of standards for the implementation of automation in the manufacturing industry. India, particularly, faces this challenge. For example, there is no unified security standard for IoT devices in India that may be parallel to the EU or US versions.

6.2 Challenges in the Indian Context

India's target of achieving a 25% contribution to GDP from the manufacturing sector by 2025 has not been met, with the sector contributing around 13-14% to GDP as of 2025.

India's manufacturing sector poses several specific challenges in addition to those outlined above, which can further hinder its transition to automated manufacturing. These include:

- Low internet penetration:

India has seen only 67% internet penetration across the country as of March 2024.

- Limited domestic AI compute capacity:

India hosts only 2% of global data centers despite generating 20% of global data.

- Legal challenges:

Lack of a comprehensive AI law, and lack of adherence to data privacy laws, especially among MSMEs.

- Challenges for MSMEs:

  - Outdated technology and expertise gaps cause limited awareness or willingness to implement advanced technology.
  - Challenges with respect to access to higher financing.

- Infrastructure gaps:

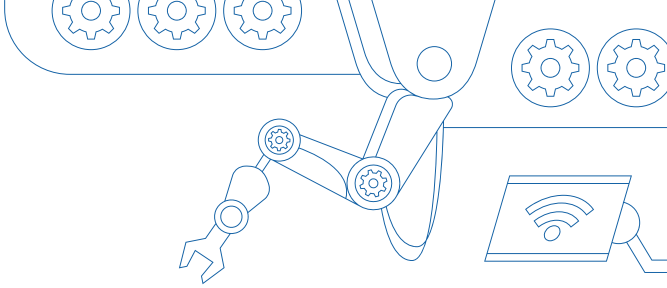
  - Disrupted supply of electricity and internet, especially in non-urban areas. According to the Central Electricity Authority (CEA), India experienced a power deficit of approximately 73,000 million units in FY 2022–23.
  - Logistical gaps, for example, issues such as a lack of last mile connectivity for supply chains.
  - Lack of standardized data infrastructure, for example, data silos. Presently, the manufacturing sector is not equipped with standardized edge or cloud computing capabilities.

- Skills gap:

  - The majority of India's manufacturing workforce presently lacks the skills and technical proficiency required to operate or maintain smart systems, such as cybersecurity, technology literacy, and human-centric skills such as problem-solving, creative thinking, and design thinking.
  - Although the transition to smart manufacturing will displace existing jobs, it will also create higher roles within the sector. However, retraining the workforce requires investment and time in training and attracting specialised talent.
  - In India, the AI market is also facing a skills gap, with the market growing at a faster rate than skilled AI talent.

In order to automate and transition India's manufacturing sector, the above challenges need to be dealt with in an integrated manner. It is important to enhance connected industries such as infrastructure and logistics and power supply, internet penetration, and digitalization of every Indian user, and to provide skilling and training for the general workforce. The government has been providing various schemes and incentives such as Make in India, SAMARTH Udyog, and the PLI schemes (covered in the above sections). These initiatives aim to inject Industry 4.0 technologies into the manufacturing sector to improve its efficiency, attract FDI, and to enhance the competitiveness of the sector in keeping with global standards.

Many initiatives are also in place to revise the curriculum at various universities and even retrain employees to equip them with the necessary skills and achieve an overall higher technological expertise within the workforce. For example, the initiatives by the National Skill Development Corporation (NSDC), Industrial Training Institutes (ITIs), or collaborations with industry bodies like NASSCOM and FICCI aim to bridge the skills gap within the manufacturing sector.



07. STRATEGIES FOR SUCCESSFUL IMPLEMENTATION OF LIGHTS - OUT MANUFACTURING

As seen in the above sections, the transition to fully lights-out manufacturing requires a very high initial investment. In determining the extent to which a company can implement automation in manufacturing, a company needs to perform a cost-benefit analysis to weigh the initial capital investment against the potential long-term returns.

In general, the implementation of fully lights-out production is more conducive for factories that carry out simple and repetitive tasks. Automating processes with complex tasks or with customized production may either prove more difficult or may not provide expected returns on investment (ROI). In most lights-out manufacturing operations, human workers are still required to manage or supervise the facility, to plan production, and oversee the process. Further, lights-out manufacturing will also mean hiring additional skilled workers in anticipation of increased production volume through automation.

The common drivers or factors of interest for companies considering implementation of lights-out manufacturing are worker shortage or increasing labour cost, and potential benefits such as improved efficiency and reduced operating costs, reduced environmental footprint, improved quality control, and enhanced global competitiveness. In a crisis such as the COVID-19 pandemic, a lights-out setup proved most advantageous since it eliminates the need for human workers, and supervision, maintenance, and the end-to-end manufacturing process and supply chain can be automated. The success cases outlined in this report have demonstrated the long-term benefits of the transition to smart, or fully automated manufacturing.

In a 2025 Deloitte survey, surveyed manufacturers indicated that AI and machine learning have the largest impact on business outcomes relative to other smart manufacturing technologies. Further, generative AI or causal AI offer the largest ROI behind cloud and software-as-a-service technologies.

In this section, we outline some strategies to consider while implementing automated manufacturing:

- Dim Factory or Lights-Sparse Manufacturing

For automating a production process, humans are generally required only to set up the machines for each production run. Lights-out manufacturing is a practical solution for large companies with a huge production volume and low variation, where small processes run over a long cycle. In such cases, a human only has to turn the machine on or begin the process and let automation take over. However, the length of time each machine can run unattended is a potential limiting factor.

Instead of implementing fully lights-out production, small and medium-sized manufacturers may consider the dim factory model, i.e., a lights-sparse factory, as a viable alternative. In this setup, only part of the production process is automated. For example, with regards to warehouse automation, a small business may opt for a conveyor system or automated guided vehicles (AGVs), whereas large companies may opt for more sophisticated AI-driven robots capable of handling multiple tasks.

- Micro-Factories

Micro-factories are small-to-medium scale manufacturing facilities that utilize automation and technology to produce a variety of products, often focusing on customization within a small volume of production. Such factories are best suited for SMEs with products that have a higher demand for customization from customers or are based on market demand. This kind of setup allows businesses to pivot on short notice to meet market demand while maintaining the return on investment.

Brownfield Vs Greenfield Automation

Brownfield projects refer to reusing or upgrading existing factories with advanced technologies, whereas greenfield implementation refers to setting up a new automated factory on undeveloped land. With respect to lights-out implementation, brownfield projects that involve retrofitting or upgrading existing systems face greater integration challenges and compatibility issues. These manufacturing facilities can still reap the incremental benefits of business-driven process automations; however, greenfield projects offer design flexibility and control over automation systems since they are designed and set up from scratch, incorporating digital or AI-powered automation without the additional cost of integration.

In 2024, greenfield projects accounted for 54.1% of the lights-out manufacturing market, according to markets.us, a market research firm.

Horizontal Vs Vertical Integration

Horizontal integration connects similar processes or departments across multiple locations, with real-time data being shared from one end of the supply chain to the other. On the other hand, vertical integration, on the other hand, connects different stages within a single factory, using technology such as sensors, AI, and data analytics. Decisions are taken autonomously by AI systems, thus optimizing workflow on the factory floor.

Robotics-As-A-Service (RaaS)

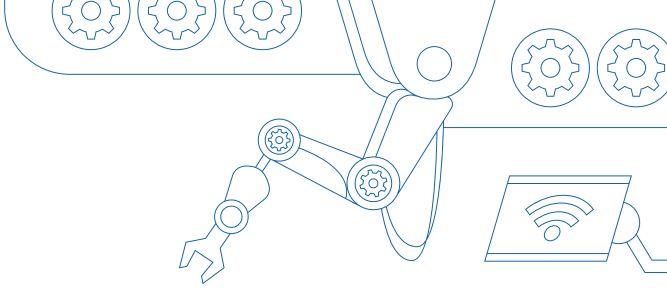
Robotics-as-a-Service (RaaS), developed on the same principles as the Software-as-a-Service (SaaS) model, allows companies to rent or lease robots on a subscription or pay-per-use basis, instead of purchasing them. This model is especially helpful for small and medium-sized companies since RaaS reduces the barrier to entry and offers a solution for challenges such as financial constraints and a lack of in-house expertise in robotics automation.

RaaS also allows flexibility in cases where product demand is seasonal or in an uncertain market. However, it is important to note that in the long term, the cost of renting robots will outweigh their potential benefits, making it more cost-effective to purchase the robots instead.

Zero-Defect Manufacturing

Aims to achieve zero defects, zero waste, and zero accidents in manufacturing by leveraging Industry 4.0 technologies like AI, robotics, and advanced sensors.

As automation and Industry 4.0 technologies are increasingly deployed in the manufacturing sector, companies considering the shift to lights-out manufacturing or some version of automated manufacturing must consider whether this shift aligns with their business vision, and not just from technological feasibility or to keep up with the global trends. Some other issues to be considered before implementation include standardisation in technology and processes, specialized employee and management training, and scalability issues.



08. THE FUTURE OF LIGHTS-OUT MANUFACTURING IN INDIA

Victor Hugo wrote, “No power on earth can stop an idea whose time has come." Automated manufacturing is no longer a model that companies must consider; it is a change that has been underway for over a decade, and it is here to stay. Manufacturers that are slow to adapt to this transformation may well face the risk of falling behind in terms of global competitive advantage.

According to a study published by the Confederation of Indian Industry (CII), although most manufacturers in India recognise technology adoption as a critical driver of profitability and competitiveness, current investments remain modest, with many allocating less than 10% of their budgets. However, the report predicts a shift towards higher investment, targeting 11-15% of budgets, in the next two years, particularly in IoT, robotics, and Big Data.

Although a full lights-out setup may not be feasible for India at this stage, India can embrace Industry 4.0, which forms the core of digital transformation. A phased implementation can be followed, for example:

- In **Phase 1,** the focus may be on digitization by integrating IoT sensors and cloud-based systems to enable real-time data collection and analytics in manufacturing units.

- In **Phase 2**, AI adoption and automation can be implemented, leveraging machine learning for predictive maintenance and process automation.

- Policy Support:

  - With the foundation for digital transformation in place, various policies by the government are helpful, such as the Production Linked Incentive (PLI) scheme targeting sectors like electronics, automotive, and semiconductors. Through automation, Indian semiconductor manufacturers can enhance precision, improve production yields, and reduce errors. Driven by demand from the EV sector and with the rollout of 5G in India, the need for advanced semiconductors is paramount, since both require specialized chips for high-speed data transmission.

  - Other than the manufacturing sector, the country is witnessing a strong focus on smart cities, smart buildings, and an overall upgrade to infrastructure, transport, and logistics. Further, sustainability is at the heart of Industry 4.0, whose technologies facilitate efficient use of resources and waste reduction. With ESG reporting standards getting more stringent around the world, smart manufacturing offers businesses all the tools for transitioning towards more efficient, sustainable manufacturing setups, and helps India meet its climate goals and transition toward greener manufacturing practices.

- Skill Development:

As mentioned in the above sections, collaborations with IITs and other industry bodies to establish training programs and an Industry 4.0-focused curriculum will help increase the expertise of the workforce.

- Financing Model:

The government may establish schemes to provide higher access to financing for MSMEs to upgrade their setup to smart technologies.

- Public-Private Partnerships (PPPs)

The National Manufacturing Competitiveness Programme (NMCP) programme helps SMEs with information and communication technology, manufacturing management, financing help, design clinics, skill development, and marketing support for SMEs. PPPs can also work to establish shared technology hubs through which MSMEs can access high-cost technologies. Such hubs can also serve as centres for R&D, training, and industry-academia collaboration.

India’s adoption of Industry 4.0 technologies and smart manufacturing is slowly but surely reshaping its factory automation market. A planned transformation of the manufacturing sector can not only help position India as a global manufacturing hub but also achieve the goal of the sector contributing 25% to India’s GDP.

KIRTANE & PANDIT

Pune

5th Floor, Wing A, Gopal House, S.No. 127/1B/ 11, Plot A1, Kothrud,
Pune – 411 038, India
Contact no : +91 20 67295100 / 25433104
E -mail : kpca@kirtanepandit.com

Mumbai

601, 6th Floor, Earth Vintage, Senapati Bapat Marg, Dadar West,
Mumbai- 400 028, India
Contact no : 022 69328846 / 47
E -mail : kpcamumbai@kirtanepandit.com

New Delhi

272, Rajdhani Enclave, Pitampura,
Delhi-110034, India
Contact no : +91-96438 74488
E -mail : kpcadelhi@kirtanepandit.com

Bengaluru

No. 63/1, I Floor, Makam Plaza, III Main Road, 18th Cross, Malleshwaram, Bengaluru – 560 055, India
Contact no : 080 23443548 / 23461455
E -mail : kpcabengaluru@kirtanepandit.com

Nashik

First and Ground Floor, Plot No. 115, Kalpataru Bunglow, SN- 315/1D, Pathardi Phata,
Prashant Nagar, Nashik - 422010
Contact no : +91 253 2386644
E - mail : kpcanashik@kirtanepandit.com

Hyderabad

401 to 405, 4th Floor, Sanatana Eternal,
3-6-108/1, Liberty Road, Himayatnagar,
Hyderabad - 500 029, India
Contact no : +91 99127 41089 / 94400 55917 / 98480 44743 / 98480 46106
E -mail : kpcahyderabad@kirtanepandit.com

Chennai

No. 128, Old No. 34, Unit No. 1, 6th Floor,
Crown Court, Cathedral Road Gopalapuram
Chennai 600086
Contact no : 044 47990259
E -mail : kpcachennai@kirtanepandit.com

Follow Us On:

kpca@kirtanepandit.com
www.kirtanepandit.com

Authored by
KP Knowledge Management Group