Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Digital Industrialisation Of MSME-Led Economic Transformation

Subramanian Ramachandran[1*], Dr. B.P. Chandramohan[2]

[1]Research Scholar, VISTAS, India; Email: subbi_r@hotmail.com*
Orchid ID: 0009-0006-9700-8480
[2]Director, School of Management Studies and Commerce, VISTAS, India; Email: director.sms@velsuniv.ac.in
Orchid ID: 0009-0003-4054-4686
**Corresponding Author: Subramanian Ramachandran*
Research Scholar, VISTAS

Consumer-driven market dynamics have the potential to impact producers, industrial ecosystem and government policies. Technological change through innovations transforms businesses resulting in increased efficiency and productivity. The rate of technological progress has accelerated more in the last two decades mainly due to information technology revolution invigorated competitive pressure and the rate of adoption and deployment of technology across various enterprises in order to achieve economies of scope and scale. In this paper, an attempt is made to show how digital enterprises and technologies influence the performance of MSME firms. Largely, the core focus is on the manufacturing sector, where the economic benefits of innovation and technological progress in digital operations of MSMEs and its domino effect on supporting business activities of the firms in the supply chain. Knowledge is critically examined to determine how digital micro and small manufacturing enterprises have a better chance to sustain competitiveness, and to move up the value chain in their effort to fulfil the national vision of self-reliance and achievement of collective operational effectiveness is also made.

Keywords: Digitalisation, Market Dynamics, Product Variability, Demand Variability, Innovation, Knowledge Dissemination, Technology Adoption, MSMEs, Modular Design.

1. Introduction

Understanding market dynamics and adapting business according to market dynamics is vital for any organisation to stay competitive in business. Organisations have to adjust their processes, products and services to changing market dynamics to stay competitive (Herrera Vidal, & Coronado Hernández, 2021). Consumer-driven market dynamics have the potential to impact producers, industrial ecosystem and government policies. This drives organisations towards innovation, and innovation improves consumer satisfaction and vice versa. Since the beginning of industrialisation, history has been replete with instances of periodic innovations and technological breakthroughs as the instruments of market dynamics. There were periodic course corrections in the form of innovations to get rid of the complexities persisting in the market.

Literature highlights that technological change through innovations transform businesses, resulting in increased efficiency and productivity boosting economic growth. Cutthroat competition often leads to cutting-edge technical advancements transforming industries and businesses significantly. Throughout the design phase, issues related to the circular economy, maintenance concerns and highest quality standards are considered. The demand for more complex and customised products is also on the rise. The increased occurrences of these call for complex solutions rather than developing and supporting a single standard product. This adds complexities in different dimensions of manufacturing, including for mid-life enhancements and aftermarket support throughout the product life cycle. Here we list out three important complexities: market, product design, and manufacturing-related technical challenges (Greco, et al., 2023). However, for manufacturing to be considered sustainable, it must be adequately supported by a sustainable supply chain (Khatri, & Srivastava, 2016). Therefore, the significance of securing resources and its flow channel triggers the linkages and nexus between enterprises. Hence, the supply chain management becomes instrumental in achieving entrepreneurship and economic development. The value chain complexity is amplified by the fragmentation of the flow of production process of individual components spread among different organisations located at distant places. Greco and others (2023) conducted a detailed study of dimensional tolerances and stress analysis of how each component interacts with each other and the entire assembly as a whole for development, manufacturability and quality control.

Business and economic performance differs both within and between different countries (Schoeffler, 1977; Sun, & Kalirajan, 2005) because each country has a unique combination of factor and technology endowment. Various firms adopt different production technologies and processes leading to imbalances in levels of technological progress and competences. This suggests that there exist varying degrees of competitive advantage, specialization in production and comparative advantage. In today’s intensely competitive business landscape, technology adoption, adaption, absorption and its continuous upgradation have become central for flexibility and efficiency (Kodama, 1991). Innovations in connectivity, data and its computational power have improved insights from processing vast amount of data and its analysis, contributing to unprecedented intelligence and decision-making capabilities. The adoption of data analysis facilitates businesses to embark on journeys of finding optimal improvement path through continuous monitoring. Digital tools like advanced analytics, machine learning and Artificial Intelligence (AI) have revolutionized operationally intensive businesses in manufacturing and in services like transportation, retail, and pharmaceutical and healthcare. These areas experience changes in their approach towards productivity, product and operational excellence to achieve long-term strategic objectives (Yoon, 2023, August 15). Digital methods and tools have a profound impact on manufacturing and industrial transformation of both society and the consumers at large.

2. Significance of the Study

Several research articles have been published related to digital transformation and IOT since the start of the COVID-19 pandemic. Majority of the articles focused on digital transformation of healthcare sector which have been deployed to combat the pandemic. Also, many papers discussed the existing and potential IOT applications used for combating COVID. In this paper, an attempt is made to show how digital enterprises and technologies influence the performance of MSME firms. Largely, the core focus is on the manufacturing sector, where there are economic benefits of innovation and technological progress in digital operations of MSMEs and its domino effect on supporting businesses activities of the firms in the value and supply chain.

3. Role of Technical Progress in the Performance of Manufacturing

Manufacturing is traditionally perceived as an expensive endeavour with significant cost centres connected with factor endowments and technology component. However, the transition from integrated to modular manufacturing has led to a change in the conventional narrative of high upfront capital investment. The paradigm shift in manufacturing process has resulted in lowering operational and overhead costs and reducing financing risk. Though modular design requires relatively more upfront technical work than the traditional manufacturing process for establishing standardization, the former offers several advantages to the firm like lower cost, scalability (both vertical and horizontal) and throughput, faster time-to-market specialization, accountability, safety, etc. (Baldea, et al., 2017). This necessitates the preparation and dissemination of comprehensive design packages comprising of detailed engineering and mechanical design of the product for the manufacturing processes, which may involve one or more enterprises. These design packages are stored in digital formats in Cloud Storage and are shared to the centres of subcontracting with production facilities, which may or may not be geographically co-located but enabling knowledge sharing. Despite the technological advances, manufacturing has been continuing with its foundational function of transforming inputs, inclusive of low-value raw materials, into marketable high-value output through the processes of value addition. This transformation into high-value products and utilities is at low cost of manufacturing owing to technical progress and exchange the same in markets for a higher profit. The basic goal of manufacturing is to earn higher profit that becomes possible through manufacturing reliable, durable, and cost-efficient products and services, besides having many other positive factors determining market demand. In the post-industrial revolution period, technological progress was attributed to being the prime factor determining the success of an enterprise. Technology has been developed across a wide range of applications in multiple industrial sectors and across different functional areas of enterprises. The rate of technological progress has accelerated more in the last two decades mainly due to information technology revolution invigorated competitive pressure and the rate of adoption and deployment of technology across various enterprises in order to achieve economies of scope and scale. Research and product development; monitoring and control of production processes, systems and business processes; and customer services have significantly evolved as a result of technical progress. Automation and digitalisation are the examples of two technologies that have significantly helped to achieve the goals of optimization, low-cost manufacturing, improve productive capacities and achieve overall organizational effectiveness. Frequent changes in product mix and demand served as a stimulus for adoption of zero-defect policy due to the consequent transformation of labour into a multi-tasking broad skilled labour force with higher levels of commitment and new forms of participation. Technological advancements have transformed the way businesses interact with each other and with production processes. Outsourcing, subcontracting and just-in-time delivery have brought the paradigm of economies of collaboration in place of scale, as modern products or equipment often require multiple manufacturing stages before final assembly

(ElMaraghy, et al., 2012). This makes the product development, individual components complexity, and its manufacturability entwined with the analysis of the complete assembly. Outsourcing and subcontracting have become valuable opportunities for the MSMEs in India to improve their efficiency and productivity.
Owing to the immense benefits of technologies, these have now come to the foray as a competitive imperative to sustain market share, rather than as a way of the future (Morgan, & Inks, 2001). Sensors, automation, robotics, virtual reality (VR), augmented reality (AR) and edge computing are transforming factory floors and how humans and machines interact and how machines and machines collaborate, enhancing productivity, safety and efficiency across various industries. A significant advantage of technological adoption is ensuring improved quality for their products and services while simultaneously dealing with the complexities of product variability associated with product design, mass production of goods and navigate the demand variability of marketplace. Enterprises experience the effects of variability across both products and their demand due to market realities and multiple product variants.

3.1 Addressing Variability

3.1.1 Manufacturing and Competitiveness
At present, product ideation is used as a process for ensuring competitiveness in manufacturing. It is a process of keeping consumer in the centre while developing a product by generating, developing and communicating new product ideas. It encompasses brainstorming, abstracting, and searching various possibilities for making or improving a new product. Hence, product design ideation is a significant decision-making phase and process for businesses, requiring careful considerations and thorough analysis of trends, evaluation and selection of production technologies. It includes new and go-to-market strategy, in addition to unexpected challenges which are brought about by economic, social and geopolitical concerns. In addition to exposure and employee experience, selection of new technologies includes iterations on cleaner greener technologies that maximise potential for material and energy conservation, minimise environmental impact, and offers chances for reskilling and upskilling among other things. Image 1 represents the various complexities associated with competitiveness.

Image 1: Complexities associated with competitiveness

Manufacturing bridges the gap between raw materials and finished goods, by transforming a low-value feed stock into a high-value finished good. A variety of materials, including metals, polymers, ceramic, and glass may be used to create a product that offers durable and aesthetic value, and affordability to the consumer. The manufacturing techniques also varies according to the choice of material and complexity of the design that can be broadly classified under microelectromechanical system (MEMS) and non-MEMS. The MEMS-based techniques involve, photolithography, chemical-etching, plating, laser fabrication, wafer bonding etc., while the non-MEMS-based manufacturing involves the traditional methods of mechanical machining, EDM, laser-cutting/patterning/drilling, embossing, injection-moulding, forging, extrusion, stamping, etc.
The necessity to optimise manufacturing techniques enabling better capability, quality and efficiency have spurred innovations in production concepts and processes. It also helps to experiment new methodologies and standards, and automation technology to develop cost-effective, precision and flexible plug-and-play solutions. The related fields of manufacturing that have gained from technological advancements are design, analysis, materials, testing, tooling, machinery, handling, assembly, inspection and manufacturing automation.

3.1.2 Product Variability

Product variabilities refer to distinct trimmed versions of a base product specifications creating a product family. This implies that multiple product configurations can be created using similar modules adjusting attributes for optimal component selection. It results in multiple product variants of a product family with scope for customisation and distinct declarative constraints, which means restriction of the product despite the common relationship. Each product variant having its unique bill of material (BOM) makes it more complex to engineer, manufacture and market. Development of modular design and production process has made it possible to meet the varieties and fluctuating demands that dynamically change over time and to reduce production cycle times. Modular design and production process permit to reduce the duration of product development and production cycle as development, manufacturing and support functions spread across multiple organisations even beyond national boundaries.
Despite the complexities of designing in manufacturing, configurability and customisation enable in meeting diverse consumer preferences scattered across various market segments. It helps to maximise customer utility, product positioning, sales, and profitability. The premium and high-end model manufacturers in automotive segment introduces product configurators to assist customers in the sales process enabling to customise products according to the specific need of the customers. This is because customers tend to compare products and services based on their characteristics such as quality of market offerings, innovation, reliability and the degree of customisation that matches their preference (Hunt, Arnett, & Madhavaram, 2006). This demands production systems to remain flexible and capable of configuring to support timely production of different products (Egyed, et al., 2023).

3.1.3 Demand Variability

The term demand variability connotes fluctuations or variations in consumer demand. It is the characteristic of the market dynamics determined by seasonal trends, change in consumer behaviour brought about by disruptive innovations, changes in preferences due to new product launches with better specifications like features, and functions, product discontinuities, outdated or obsolete models, production delays, competitor action, supply chain disruptions, etc. (WallStreetMojo., 2024, January 25). Innovations in modern production systems enable quick reconfiguration of production processes unique to the product and offering flexibility to alter designs and products fast. Meeting variable demands might at times make it necessary to undertake manufacturing in small-run batches for order fulfilment. This has led to ripple effect innovations in optimising production resources through supply chain management (SCM) and other support functions essential for smooth production and product flows, and for sparing customers from waiting long, all while defying the logic of economies of scale and being cost-effective.

3.2 Flexible Technologies for Manufacturing

Technology has percolated shop floors that churn out both high-volume consumer products and low-volume bespoke parts contributing to specialised parts and subsystems. This distinguishes each industry, the businesses that operate in them, and the technology (Lauzier, 2022, August 18). Irrespective of the industry and the marketed product, increasing customer base and improving market share are formidable challenges businesses face. It has a direct proportional effect on productivity, capacity utilisation and achieving higher levels of overall equipment effectiveness (OEE). In order to meet the diverse needs of market segments, and to satisfy their diverse requirements for products and services, organisations that strives to sustain its market share today must carefully oversee their supply chain, utilise modular design in product development, and strategically plan appropriate flexible production technologies to match anticipated production volumes throughout the product's life cycle.

3.3 Continuous Innovation and Adaptive Manufacturing

Continuous innovation to upgrade modern technologies has brought about configurable production systems and procedures that are nimble by design to quickly adapt to the callings of change without hindering production process. Modern manufacturing factories are reminiscent of assembly lines congested with automated integrated tandem and sequential processes employing computer numeric control (CNC) machine and robots. They produce simple-to-complex components with varying degrees of autonomy and assemble them into finished products within the acceptable tolerance of accuracy. Monitoring and controlling machines and equipment remotely using sensors and control loops provide improved efficiency, accuracy and productivity through centralized or dedicated controllers using computers.

Technology offers immense potential for optimization; for instance, predictive maintenance and precise condition monitoring using artificial intelligence (AI) increases asset life, increases uptime, minimizes unexpected downtime, and improves maintenance practices, all of which supports the practice of reliability-cantered maintenance (RCM). Technology has also creeped into other functional areas of an organisation like supply chain and logistics, marketing, sales and retail, accounting and finance due to its ability to improve productivity, efficiency and effectiveness of both the personnel and the organisation. Studies suggest that continuous technology initiatives and improvements are greatly contributing to the bottom-line performance, sustainability, and resilience of an enterprise and an evolved workforce that is adept at using digital tools (Speier, & Venkatesh, 2002).

4. Modular Manufacturing Technique Led Structural Transformation

The 20th century ushered neo-liberal coproduction paradigm that fragmented traditional production processes in matured industries into distributed, disintegrated yet interconnected production processes beyond national boundaries among several companies (Gereffi et al. 2001, 2005; Grossman & Rossi-Hansberg., 2012), thanks to modular manufacturing technique. This augmented MSMEs prospects to participate in the global economy (Epede, & Wang, 2022) and accelerated the growth of trade in raw materials and intermediate feed inputs (Kevin Cheng, et. al., 2015; Cezar, et. al., 2017). And this was well complimented by declining trade barriers that eased movement of capital, labour, and technology (Dowlah, 2020). These aspects brought about three important changes to the global economy.

i) Dramatically increased the competition.
ii) Drastically shrunk the cycle time for developing new product and get them to market.
iii) Efficiency improvements due to pricing pressure.

When taken as a whole, these economic models have positively impacted technological progress, reduced skill differential, increased skill demand, generated employment opportunity and improved labour markets, all of which contributed to structural transformation (Borjas, 1995; Feenstra, & Hanson, 1995; Guha-Khasnobis, et al., 2023). For organisations, collaborations proved mutually benefiting. The MNCs achieved higher productivity at reduced cost, which led to increased efficiency, while their affiliate MSMEs benefited from new knowledge that enhanced capabilities, design thinking and innovation. According to Micheal Porter, nation's economic competitiveness is determined by its capacity to establish favourable business environment.

4.1 Globalisation Counterintuitive to Domestic Manufacturing

Globalisation called into question the widely recognised concepts of factor endowment and opportunity cost. For instance, domestic industries extract and convert spatially dispersed natural ore into refined and concentrated ore. Today, mineral extraction and its value addition through intermediate processing and transformation into final product is distributed globally in factories across borders. When taken at face value, globalisation is a great proposition, as it delimits trade and commerce beyond neighbourhood. Also, it improves linkages and successfully integrates MSMEs into labour-intensive upstream sector of global supply chains. Moreover, globalisation allows to specialize in areas of competitive advantage on non-core technological tasks like extraction and assembling sub-systems into finished goods adding domestic value, thereby benefit from knowledge-sharing spill-overs, upskilling and sector modernisation. However, bulk of the value addition and core technologies are carried out downstream of the supply chain. Despite changing market dynamics and shorter product lifecycle, the MSMEs engaged in GVC refrain from engaging in incremental and radical innovations limiting potential and the opportunity to establish an indigenous brand. Perhaps, a possible reason might be the fear of failing stemming from a lack of in-depth knowledge of the intricacies of each component prior to it being assembled into the final product, which is

necessary to enable a seamless shift to the more complex, high-tech advanced manufacturing techniques.
If globalisation challenged the widely recognised concept of factor endowment, liberalisation plays a vital role in knowledge, skill, and technology transfers through MNC spin-offs determining technology choice (Lin, et al., 2023). In other words, "dictating technology choice" further adjusts and upgrades the industrial structure. Technology progress, location and non-geographic factors trigger subsequent growth spurts of MSMEs. Emerging new high-tech industries decide technological advancements near the point of consumption and produce high-quality and cost-effective products to gain market share (Ignatenko, et al., 2019). Future industrial development and upgrading will thus be driven by the potential for autonomous innovation capacity, an optimal industrial ecosystem with developed ICT, and a well-developed supply chain and logistics (Ye, 2011; Dou, et al., 2021). Liberalisation at its face value is not a poor decision; however, it is criticised because trade liberalisation displaces livelihood and disrupts lives. Since innovation spurs manufacturing and becomes the foundation of manufacturing, liberalisation disassociates with factor endowment characterised by comparative and competitive advantage endangering sustained growth of the local manufacturing sector. Geopolitical economic rivalry between nations is another important factor to consider. As a result of this competition for supremacy and leadership in core-technology, it has already gained the same degree of geo-strategic relevance as global trade and military alliances. Restrictive policies and export controls can limit access to critical technologies for businesses in the global south to survive and perhaps raising costs for the consumers.

4.2 COVID-19 Activated the Wakeup Call

Post COVID supply chain disintegration, the global rhetoric of political economy is back on highlighting the significance of manufacturing in their national economy to build a healthier and diverse economy. The emphasis has shifted from economic rivalry to technological excellence and reign supremacy to safeguard national and economic interest due to geo-political concerns. National security is a compelling rationale and discussion of it often overlooks its effects on the business environment (Ando, et al., 2024). A growing number of countries and companies are taking actions to rebuild their manufacturing sector, to reduce strategic dependence, yet remains both sustainable and resilient. The Economic Advisory Council to the PM, India has identified food, energy and defence as three key strategic sectors to improve self-reliance and immunize these sectors from instabilities caused by geo-political events and economic shocks while strengthening social safety nets (Shamika Ravi., 2023).
This phase also witnessed higher adoption and the growth of Internet of Things (IOT) across multiple industrial sectors like manufacturing, healthcare, telecommunication, retail, transport services, hospitality, etc. complemented by a developed information and communication technology (ICT) infrastructure (Abdullah, & Abdullah, 2021). Prior to the disruptions brought on by the pandemic, digital transformation and IOT adoption were progressing slowly, despite the concept's popularity, proven use cases and anticipated benefits. The lockdown and adaptation to new normal expanded use cases for digital technologies and IOT and organisations prioritized their implementation, with the lockdowns turning out to be a catalyst for digital revolution (Umair, et al., 2021).

5. Digital Technology Advancement as an Enabler

5.1 Digital Enterprises and Digital Industrialisation

Digital tools enhance capabilities and efficiencies. They are used for data collection, analysis, collaboration and innovation. Digital enterprises collect data to monitor, measure, and optimise various aspects related to design and development, manufacturing and business operations to improve efficiency, quality, productivity and organisational effectiveness. Digital tools enable experimentation with new production processes including plant and facility layout, simulation of process operations, and fine-tune operations without any risk or loss to improve possibilities for resource utilisation and to minimise waste. These functionalities empower to analyse, learn, protect and simulate, thus support creation of vast number of compelling use and business cases that ultimately redefine how businesses establish and standardise products and processes. Benefits of digitalisation are not only limited to improved visibility but also help in data-driven decision making, process optimisation, and customer satisfaction.

Legacy industries like manufacturing, pharmaceutical and healthcare, hospitality, transportation and logistics, distribution and retail, travel and leisure are industries that are operationally intensive with relatively more opportunities for disruption and are better equipped with strong foundation in IT, operational technology, and data infrastructure.

As a result, they have increased their reliance on automation and digital technologies to improve customer experience. These industries, in particular manufacturing and pharmaceutical, require significant capital investment for cutting-edge innovations. Adoption of digital technologies early on in the product development cycle has the potential to improve reliability and reduce development time and R&D cost involved in new product development, thereby reducing the risk associated with payback and time to market.

5.1.1 Digitalisation in Healthcare Touched Common man

During the COVID lockdown, it was witnessed that public health systems, academic institutions and states came together to invent, produce and distribute vaccines in billions to saving millions of lives (Lathan, 2023, March 30). Historically, inventing vaccines have taken eight to ten years, involving extensive research followed by clinical trials, regulatory approvals, and finally manufacturing and distribution. The COVID vaccines went through all the stages in less than one year. This situation witnessed unprecedented combination of industrial-scale performance and flexibility - the differentiator that digital tools offer. In addition to this, several innovative digital technologies were introduced with mobile interface in the healthcare sector as follows:

i) Track and contact trace
ii) Handheld portable diagnostic devices.
iii) Contactless telehealth services
iv) GPS bracelets for tracking confinements
v) Autonomous disinfectant robots
vi) Visitor management and tracking
vii) Vaccine management

Many of these innovations touched common man in his day-to-day functions.

5.1.2 Digitalisation in Manufacturing

Digital technology is a powerful tool as an enabler for innovation and efficiency improvements, thereby digital tools have the potential to accelerate innovation throughout the product lifecycle. While product lifecycle can vary from product-to-product and for industries, it can be broadly articulated in two discreet stages with multiple sequential and dependent phases within each stage: (a) pre-release and (b) post-release

The pre-release stage comprises of conceive, design, test and optimise, secure supply chain, and manufacture. While the post-release stage comprises of after-market maintenance support, periodic upgrades and phase-out, and end-of-life disposal including salvage to recycle, retire and obsoletion. Digital technologies help integrate these two discreet stages to have business maintain better control over the entire product lifecycle and document management, i.e. help archive and exchange data over web-based systems including revisions for publishing and printing.

Digital design, development and manufacturing is fundamentally better than the conventional process. It is aided by digital tools like computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), computer-aided quality (CAQ), virtual and augmented reality that aids to digitally model, iterate a product, simulate failures for analysis, optimise, generate BOM, create tool designs and selection plans and machining instructions, workflow management, production planning, monitoring and control, engineering change management, etc., all of which makes it possible to not just develop and deliver faster but also better.

Likewise, automation and edge computing devices like sensors and gateways, robotics and other IoT devices have increased computational resources enhancing analytical capabilities of the end user. In addition to improving predictive maintenance, this has transformed production floors on how humans and machine interface to collaborate and how machine-to-machine coordinate enhancing efficiency. Additionally, it assists in controlling errors and maintain precision by digitally qualifying manufacturing processes and finished parts as quality control is carried out in-situ. As a result, digitalisation guarantees that a product quality is known when it emerges as a finished product and enables the development of processes, procedures and configurations for further optimisation. This allows organisations to be armed with a product development lifecycle that is much faster and use resources more efficiently. Additionally, to improve technology, digital manufacturing also collects data of both the product and the production processes for every product produced. Analysing the design and manufacturing process data will help optimize the production process to improve competitiveness.

6. MSMEs and Technological Progress

There is a positive causal relationship between GDP and MSME output (Dixit & Pandey, 2011). Prior to 1991, Indian economy underperformed under the closed protectionist economy because businesses underinvested in technology and innovation relative to social optimum. Lall (1984) argued that protectionist policy, while fostering the creation of a diverse industrial base, also contributed to inefficiency and technological backwardness, hindering realisation of technological capabilities and therefore comparative and competitive advantage. This made it more difficult for the market mechanism to turn competitive. This was also partly due to the fact that micro and small businesses often lacked the funds, expertise, and time necessary for technological modernisation or adoption of new technologies and practices that improve worker skills, competency, productivity and quality compliance for profit maximisation. All these factors affected the industry sector's performance. According to Economic Survey 2018-19, large business that make up just 15% of the organised sector generates 90% of productivity and three-quarters of permanent employment. In contrast, small businesses which account for more than half of organised manufacturing contribute only 8% and 14% to productivity and employment, respectively.

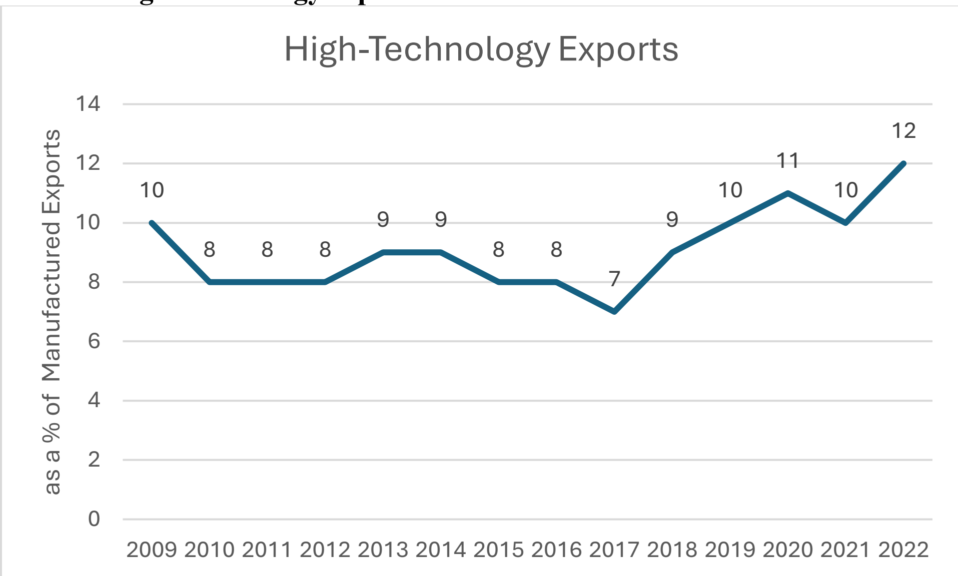
The post reform era being more market-driven guided by profit-maximising frameworks, the focus shifted to prioritising industrial productivity and technological prowess above self-reliance and indigenisation (import substitution) of technology. MSMEs focused on technological upgradation for:

i) Survival and to protect its interest by retaining market share.
ii) Improve competitiveness to forge new relationships.
iii) Establishing compatibility with global supply chains to bridge technological gaps.

Technological advancements have significantly impacted the previously labour-intensive textile and leather industries becoming capital-intensive, leading to a shift in production patterns, a decrease in labour-intensity and an increase in capital-intensity (Chaudhuri, 2002; Tandon, 2019). In the post reform period, capital and skill-intensive industries have expanded faster relative to labour-intensive micro and small enterprises. As a result, the labour share of economy declined from 54% in 1980 to 49% in 2016 (Anwesha Basu, & Veeramani, 2021). However, regulating technological diffusion can be challenging because medium and large, and micro and small enterprises have different equipment needs when it comes to applicability of technology, and throughput. This is because large and medium enterprises assemble intermediate goods produced by micro and small enterprises. Thus, the degree of technology diffusion will inevitably vary across different industrial sectors and will depend on the size of the firm. Another key aspect is the technological convergence due to globalisation and growing interdependence for comparative advantage, characterised by patterns of technological specialisation also makes technological diffusion distinct across different countries and firms. The study by Desai (1984) makes a distinction between modular and integrated manufacturing industries; his research finds significant capability development in the former. For the lag in capability development in the integrated industries, his study identified lack of coordination skills, high prevalence of trading among entrepreneurs, low-quality engineering education, numerous small plants and non-standard technology imports.

The disproportionate capability development in the modular manufacturing indicates comparative technological advantage in low-end mass manufacturing due to workforce competency and production efficiency, i.e. technological capability rather than due to technological development or innovative capacity (Bhaduri, & Ray, 2004). However, India has shown remarkable competency in high-end information-intensive manufacturing and services like pharmaceutical, electronics, aerospace, medical devices, finance, and software shifting into knowledge economy (Ray, 2008). As of 2019, high-tech manufacturing contributed 34.23% of total domestic manufacturing output which is less than 3% of global output of high-tech manufacturing industries achieving an equivalent indicator rank of 35. The share of high-tech exports has been on the rise and had crossed USD 27 billion in 2021 (WIPO, 2023). Chart 1 below shows the share of high-technology exports from India as a percentage of total manufactured exports.

Chart1: High-Technology exports - India



Source: World Bank Group

For economies to move up in the value chain beyond basic industrial processes, higher education is considered essential. Tertiary education in science, engineering, manufacturing and construction are crucial for acquiring better knowledge and skills necessary to meet the exacting standards of high-tech manufacturing and for innovation. High-tech manufacturing is expected to generate knowledge-intensive employment which stood at 13% in 2022 down from 14.2% in 2018 ranking 99th and 91st, respectively. This decline in knowledge-intensive employment is a sign of feebleness, despite India ranking 11th in the world for producing 34% of all tertiary graduates in the disciplines of Science, Technology, Engineering and Mathematics (STEM) (PIB, Sep 29, 2023; WIPO, 2023 & 2018). However, India has made a significant stride in the Global Innovation Index (GII) from its 81st position in 2015 to 40th position in 2023 (PIB, Sep 28, 2023). The steady rise in GII indicates build-up of vast amounts of knowledge capital. GII - 2023 report mentions that Bengaluru, Chennai, Delhi and Mumbai are the most intensive Science and Technology clusters, i.e., high concentration of industries involved in high-tech manufacturing and innovation in India. Global corporate giants have established their global capability centres (GCC) to provide business-support functions including product design and development and handle back-office functions, including remote IT infrastructure, to sustain their productivity growth. This implies that India is a favoured destination for global large corporate investors. According to GII, in 2023, India ranks 13th in terms of allocation for average R&D expenditure by the top three firms that reflect in the top 2500 global R&D investors.

Innovations provide long-term sustainable solutions to the current and futuristic issues challenging India and rest of the world, such as increasing urban pollution, water scarcity, rising sea levels across various regions, depletion of natural resources, climate change concerns and food waste. However, Indian MSMEs fall short when it comes to process innovation since they prioritise market-driven strategies above the development of innovative products (Satish, et al., 2020). Evolutionary economic theory suggests technological advancement stimulates economic development through its three pillars: invention, commercialisation of innovation and knowledge diffusion. And therefore, despite a proven track record of invention and innovation, failure to effectively disseminate knowledge can cause a business, industry sector or country to lag behind its competitors. In the modern days, due to higher emphasis on flexibility, adaptability and increased information-intensive nature of operations, we witness rapid innovations in production systems that enables businesses to quickly respond to market dynamics. Under these circumstances, knowledge and its effective dissemination has emerged as a critical resource and a catalyst for MSMEs seeking to leverage innovation for sustained performance and to achieve competitive advantage (Thomas, & Gupta, 2022).

An employee's expert knowledge, experience, and skill, present in ideas, intuition and insights is characterised as the intellectual capital and it is the driver of organisational performance. It is an intangible and invaluable resource created, organised, disseminated and applied or exploited for innovation, survival from unpredictable events, growth, and organisational development and to improve and sustain competitive advantage to enhance organisation performance and create customer value (Davenport, & Prusak, 1998; Hussein, et al., 2016; Taipale-Erävala, et al., 2019; Adesina, & Ocholla, 2024). The organisational knowledge exists in silos in three forms: explicit, implicit and tacit. Knowledge management is crucial for MSMEs as they are more adaptable and receptive to new ideas than bigger organisations (Wang, & Yang, 2016). However, due to rapid technological advancements, MSMEs are grappling with unprecedented challenges in knowledge management, maintaining competitiveness and sustainable performance. It is therefore crucial to emphasise here that most businesses find it difficult to distinguish between the three related concepts (data, information and knowledge) and use them interchangeably, whereas these are distinct ideas that cannot be substituted.

All organisations capture and store data to maintain records of discreet events, transactions, incidents, accidents etc., organised in a structured manner. Data with context, relevance and purpose adds meaning and insight to it and transforms it into information. It is information that moves around in an organisation through various mediums like notice, messages, announcements, a note-on-file or emails. Infrastructure for data storage and networked computers have opened up potential opportunities for information exchange in real-time. Interpreted or reasoned information is knowledge that is a conceptual grasp of the circumstances which serves as the foundation for well-informed decision making for the necessary activities required to accomplish the goals. Information and knowledge sharing in business usually happens during training, formal and informal meetings, and social interactions within and outside workplace boundaries, as opposed to relying exclusively on manuals and textbooks (Easa & Fincham, 2012). Additionally, processes, teamwork, networks, systems and technologies linked to ICT like IOT and Electronic Data Interchange (EDI) also trigger this exchange (Alves & Pinheiro, 2022) for CAD/CAM or other relevant product lifecycle data. According to GII 2023, of the 132 countries, India ranks 103 and 101 for ICT use and access by businesses, respectively, which is a detractor. In contrast, Government of India (GoI) fares better in ICT utilisation for delivering its e-governance services ranking 42. This suggest that ICT use cases can be envisaged in the areas of social transformation and well-being in addition to productivity, efficiency and economic growth.

Micro and small enterprises serve as contract manufacturers to medium and large enterprises, thereby are uniquely positioned to inherit predefined knowledge. Due to the nature of their hierarchical relationship, collaboration and the need for high degree of coordination regardless of the information, being of proprietary nature is shared as the first step. The information exchanged is product/engineering data (ED) which are engineering drawings with product dimensions and specifications, bill of materials, manufacturing resources which includes tools, jigs and fixtures, workflow, process and machining instructions, inspection and quality control, etc. Digital tools like CAD through 2D drawings and 3D models breathe intelligence as they help visualise complex geometries and design intensions of the product. This helps organise knowledge to build capabilities on various types of activities throughout the process workflow and various procedures. This helps improve competitive advantage needed to enhance functionality of the existing products or services or to conceive and develop new ones. Thereby knowledge sharing is instrumental in helping build a knowledge-centred workplace where every agent's action is oriented, deliberate and meticulous as he works on verified and sustainable information hence repeatable until new set of procedures and practices are implemented. In addition to it, traceability of publication of midlife upgrades and modifications to the initial spec are validated for reception. Digital tools aid in archiving documents in a structured manner and retrieve them as on need basis.

Automation allows for the effective completion of repetitive and complex tasks, while digitisation and digitalisation help proactively collect, archive data related to various process parameters and events of operational significance for further analysis to enrich knowledge. However, ensuring existence and availability of data at will may not suffice, knowing what events to monitor, collect which parameters, what to analyse, how to interpret, what reports to publish and making that knowledge accessible in real-time instantly on preconfigured dashboards is what counts. Continuous monitoring enhances process visibility and makes it possible for the supervisor to remotely and continuously observe machines or control areas throughout the factory floor, which serves as the foundation for acquired knowledge. In addition, automation enables to quickly reconfigure autonomous control systems needed for measurement and adjustment required to control the equipment used for continuous or batch processes. Market dynamics dictates the need for change management thereby triggering the requirement for traceability to monitor and verify the progress meets the requirements. Control automation improves scalability, quality, safety, reliability and cost-effectiveness improving sustainability and resource efficiency, all while minimising human intervention.

Given below are few digital tools commonly used in businesses that are in continuous pursuit to optimise processes and operations to improve organisational effectiveness, profitability and sustainability:

i) Process Control Automation & Dashboards: Used for repetitive tasks, reducing manual intervention, and human errors. While interactive dashboards provide real-time visibility into process metrics and make adjustments if required. It reduces intervention lead time and optimises resource utilisation.

ii) Internet-of-Things (IoT): It enables real-time monitoring and insights into equipment, processes and products. Proactively identifies issues and data driven improvement.

iii) Project Management Software (PMS): Helps organise and track project progress. Helps with task allocation, set timelines, monitoring progress and objectives are met according to schedule.

iv) Customer Relationship Management (CRM): It serves as a central repository for customer profiles, sales, and marketing. It helps analyse, sales pipelines and marketing campaign effectiveness and lead management.

v) Enterprise Resource Protocol: It serves as a central repository for inventory management, finance, sales, procurement and production data.

Digitisation and digitalisation enable to capture and analyse process and operational data, MSMEs acquire knowledge through experience and observation both of which significantly impact learning capacity. Analysis of experience and observations helps with in-depth understanding to reach well-informed conclusions and approach problem-solving more effectively thereby hone skills. Both inherited and acquired knowledge collectively shape the skills, adaptability, and responses of a business apart from creating a conducive environment for experimentation and innovation. Unlike inherited knowledge, acquired knowledge is flexible, easier to unlearn, modify, relearn and disseminate giving the power to develop a knowledge-centred organisation. Acquired knowledge, therefore, is a powerful tool that can push the boundaries of organisational capability for innovation capacity.

One of the major transformations brought about by globalisation, is the decoupling of the product and process innovation which enabled organisations to scale. The large business or Original Equipment Manufacturers (OEM) took ownership of the former. It is in the self-interest of the MSMEs to bring about innovation in manufacturing processes to continue as manufacturing partners, as this is what is needed to build and maintain comparative edge. With access to both inherited and acquired knowledge, MSMEs knowledge pool can be related with that of the erstwhile integrated manufacturers, this offers them the advantage to launch their own brand and proliferate the market. If MSMEs leverage digitalisation to its fullest capacity, the future unlike today may not be handful of large brands but swarms of brands offering products at competitive prices benefiting consumers. Increased ICT adoption and usage, automation and digitalisation can go a long way in realising this.

7. Conclusion:

In this paper we focused on the complexity of product development and manufacturing and explored the possibilities of how technology including digitalisation can help overcome challenges throughout the complex lifecycle of a product apart from contributing to competitive and comparative advantage by enhancing innovation capacity. As MSMEs form an integral part of the value chain, they are uniquely positioned to inherit knowledge in the form of technology diffusion and knowledge spill-overs. Technology upgradation for modernisation therefore becomes an essential imperative for acquiring new knowledge, continued collaboration and to sustain competitiveness and to move up the value chain. In this aspect, one of the key challenge countering MSMEs modernisation is low ICT use and access. Lack of network connectivity is a detractor for process control automation, digitisation and digitalisation severely impairing capacity utilisation, adaptability, scalability, comparative advantage, sustainability and importantly acquire new knowledge. Digital tools create new opportunities, reduce development time, and improves reliability by continuously redefining processes and standards.

References

Journals

1. Abdullah, M. A., & Abdullah, M. A. (2021). How COVID-19 Has Affected the Internet of Things (IoT) Technology. 2021 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), 1–6. https://doi.org/10.1109/SOLI54607.2021.9672416
2. Adesina, A. O., & Ocholla, D. N. (2024). Tacit knowledge management strategies of small- and medium-sized enterprises: An overview. SA Journal of Information Management, 26(1). https://doi.org/10.4102/sajim.v26i1.1711
3. Alves, R. B. C., & Pinheiro, P. (2022). Factors Influencing Tacit Knowledge Sharing in Research Groups in Higher Education Institutions. Administrative Sciences, 12(3), 89. https://doi.org/10.3390/admsci12030089
4. Ando, M., Hayakawa, K., & Kimura, F. (2024). Supply Chain Decoupling: Geopolitical Debates and Economic Dynamism in East Asia. Asian Economic Policy Review, 19(1), 62–79. https://doi.org/10.1111/aepr.12439
5. Baldea, M., Edgar, T. F., Stanley, B. L., & Kiss, A. A. (2017). Modular manufacturing processes: Status, challenges, and opportunities. AIChE Journal, 63(10), 4262–4272. https://doi.org/10.1002/aic.15872
6. Bhaduri. S. & Ray. A.S. (2004). Exporting Through Technological Capability:Econometric Evidence from India's Pharmaceutical and Electrical/Electronics Firms. Oxford Development Studies, 32(1), 87–100. https://shorturl.at/nU1jK
7. Borjas, G. J. (1995). The Economic Benefits from Immigration . Journal of Economic Perspectiv, 9(2), 3–22. https://scholar.harvard.edu/files/gborjas/files/jep1995.pdf
8. Chaudhuri, S. (2002), "Economic Reforms and Industrial Structure in India", Economic and Political Weekly, Vol. XXXVII, No. 2, pp. 155-162. (PDF) Economic Reforms and Industrial Structure in India (researchgate.net)
9. Desai. A.V (1984). Achievements and Limitations of India's technological Capability. In Martin Fransman & Kenneth King (Eds.), Technological Capability in the Third World (pp. 245–261). Macmillan. https://quillbot.com/paraphrasing-tool?utm_source=paraphrasing-
10. Dixit. A., & Pandey. A.K., (2011): SMEs and Economic Growth in India: Cointegration Analysis. The IUP Journal of Financial Economics, Vol. IX, No. 2, June 2011, pp. 41-59, Available at SSRN: https://ssrn.com/abstract=2059875
11. Dowlah. C., (2020). Cross-Border Labor Mobility. In Cross-Border Labor Mobility: Historical and Contemporary Perspectives (pp. 243–275). Springer International Publishing. https://www.academia.edu/85693196/Cross_Border_Labor_Mobility
12. Dou, Z., Wu, B., Sun, Y., & Wang, T. (2021). The Competitiveness of Manufacturing and Its Driving Factors: A Case Study of G20 Participating Countries. Sustainability, 13(3), 1143. https://doi.org/10.3390/su13031143

13. ElMaraghy, W., ElMaraghy, H., Tomiyama, T., & Monostori, L. (2012). Complexity in Engineering Design and Manufacturing. CIRP Annals, 61(2), 793–814. https://doi.org/10.1016/j.cirp.2012.05.001
14. Greco, A., Manco, P., Russo, M. B., & Gerbino, S. (2023). Complexity-driven product design: part 1—methodological framework and geometrical complexity index. International Journal on Interactive Design and Manufacturing (IJIDeM). https://doi.org/10.1007/s12008-023-01426-1
15. Gereffi, G., Humphrey, J. & Sturgeon, T. (2005), ‘The governance of global value chains’, Review of International Political Economy 12(1), 78–104.
16. Gereffi, G., Humphrey, J., Kaplinsky, R. & Sturgeon*, T. J. (2001), ‘Introduction: Globalisation, Value Chains and Development’, IDS Bulletin 32(3), 1–8
17. Grossman, G. M. & Rossi-Hansberg, E. (2012), ‘Task trade between similar countries’, Econometrica 80(2), 593–629.
18. Guha-Khasnobis, B., Aditya, A., & Chandna, S. (2023). Employment and Global Value Chain Participation: The Indian Experience. International Journal of Economic Policy Studies, 17(1), 75–94. https://doi.org/10.1007/s42495-022-00092-7
19. Herrera Vidal, G., & Coronado Hernández, J. R. (2021). Complexity in manufacturing systems: a literature review. Production Engineering, 15(3–4), 321–333. https://doi.org/10.1007/s11740-020-01013-3
20. Hunt, S. D., Arnett, D. B., & Madhavaram, S. (2006). The Explanatory Foundations of Relationship Marketing Theory. Journal of Business & Industrial Marketing, 21(2), 72–87. https://doi.org/10.1108/10610420610651296
21. Hussein, A. T. T., Singh, S. K., Farouk, S., & Sohal, A. S. (2016). Knowledge sharing enablers, processes and firm innovation capability. Journal of Workplace Learning, 28(8), 484–495. https://doi.org/10.1108/JWL-05-2016-0041
22. Khatri, J., & Srivastava, M. (2016). Technology selection for sustainable supply chains. International Journal of Technology Management & Sustainable Development, 15(3), 275–289. https://doi.org/10.1386/tmsd.15.3.275_1
23. Kevin Cheng, Sidra Rehman, Dulani Seneviratn, & Shiny Zhang. (2015). Reaping the Benefits from Global Value Chains (15/204; Asia and Pacific Department). https://shorturl.at/BoC2w
24. Lin, J. Y., Liu, Z., & Zhang, B. (2023). Endowment, technology choice, and industrial upgrading. Structural Change and Economic Dynamics, 65, 364–381. https://doi.org/10.1016/j.strueco.2023.03.002
25. Epede, M. B., & Wang, D. (2022). Global value chain linkages: An integrative review of the opportunities and challenges for SMEs in developing countries. International Business Review, 31(5), 101993. https://doi.org/10.1016/j.ibusrev.2022.101993
26. Morgan, A. J., & Inks, S. A. (2001). Technology and the Sales Force. Industrial Marketing Management, 30(5), 463–472. https://doi.org/10.1016/S0019-8501(99)00115-7
27. Rafael Cezar, Guillaume Gaulier, & Vincent Vicard. (2017). Competition for Global Value Added: Export and Domestic Market Shares (628). https://shorturl.at/t0PGc
28. Ray. A.S. (2008). Emerging through Technological Capability: An Overview of India’s Technological Trajectory (227). https://www.econstor.eu/bitstream/10419/176245/1/icrier-wp-227.pdf
29. Satish B. Gunjati, & C.V. Adake. (2020). Innovation in Indian SMEs and their current viability: A review. Materials Today: Proceedings, 28(4), 2325–2330. https://sci-hub.st/10.1016/j.matpr.2020.04.604
30. Schoeffler, Sidney (1977), "Nine Basic Findings on Business Strategy," The PIMSLETTER on Business Strategy, 1.

31. Shamika Ravi. (2023). Making India Self-Reliant (EAC-PM/WP/19/2023; EAC-PM Working Paper Series). https://www.eacpm.gov.in/wp-content/uploads/2023/07/19-Atmanirbhar-India.pdf
32. Speier, C., & Venkatesh, V. (2002). The Hidden Minefields in the Adoption of Sales Force Automation Technologies. Journal of Marketing, 66(3), 98–111. https://doi.org/10.1509/jmkg.66.3.98.18510
33. Sun, C., & Kalirajan, K. P. (2005). Gauging The Sources Of Growth Of High-Tech And Low-Tech Industries: The Case Of Korean Manufacturing*. Australian Economic Papers, 44(2), 170–185. https://doi.org/10.1111/j.1467-8454.2005.00258.x
34. Taipale Erävala, K., Lampela, H., & Henttonen, K. (2019). Entrepreneurial competencies in successfully innovative SMEs. International Journal of Entrepreneurship and Small Business, 38(3), 251. https://doi.org/10.1504/IJESB.2019.10025041
35. Thomas, A., & Gupta, V. (2022). Tacit knowledge in organizations: bibliometrics and a framework-based systematic review of antecedents, outcomes, theories, methods and future directions. Journal of Knowledge Management, 26(4), 1014–1041. https://doi.org/10.1108/JKM-01-2021-0026
36. Umair, M., Cheema, M. A., Cheema, O., Li, H., & Lu, H. (2021). Impact of COVID-19 on IoT Adoption in Healthcare, Smart Homes, Smart Buildings, Smart Cities, Transportation and Industrial IoT. Sensors, 21(11), 3838. https://doi.org/10.3390/s21113838
37. Wang, M.-H., & Yang, T.-Y. (2016). Investigating the success of knowledge management: An empirical study of small- and medium-sized enterprises. Asia Pacific Management Review, 21(2), 79–91. https://doi.org/10.1016/j.apmrv.2015.12.003
38. Ye Hong-tao. (2011). Modularity and the path of industrial transformation and upgrade in China. 2011 International Conference on Business Management and Electronic Information, 66–69. https://doi.org/10.1109/ICBMEI.2011.5916858

Books

1. Egyed, A., Grünbacher, P., Linsbauer, L., Prähofer, H., Schaefer, I. (2023). Variability in Products and Production. In: Vogel-Heuser, B., Wimmer, M. (eds) Digital Transformation (pp. 65–91). Springer Vieweg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-65004-2_3
2. Kodama, F. (1991). Analyzing Japanese high technologies : the techno-paradigm shift. Pinter Publishers.

Reports

1. WIPO. (2018). Global Innovation Index (GII) India - 2018. https://www.wipo.int/edocs/plnkdocs/en/wipo_pub_gii_2018_in.pdf
2. WIPO. (2023). The Global Innovation Index (GII) India - 2023. https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2023/in.pdf

Working Paper

1. Tandon, A., (2019). Assessing Factor Proportions in Tradable Sectors of the Indian Economy (212). https://isid.org.in/wp-content/uploads/2020/04/WP212.pdf
2. Anwesha Basu, & C Veeramani. (2021). Labour Share in Indian Economy: An Exploratory Analysis of the Role of Trade, Technology, and Structural Transformation (WP-2021-027). http://www.igidr.ac.in/pdf/publication/WP-2021-027.pdf

Webpages

1. Davenport, T. H., & Prusak, L. (2000, August). Working knowledge: How Organizations Manage What They Know. https://doi.org/10.1145/347634.348775
2. Lauzier, J. (2022, August 18). Machine Utilization: Track and Improve Equipment Performance. Machine Metrics. https://www.machinemetrics.com/blog/machine-utilization
3. WallStreetMojo (E.D) Dheeraj Vaidya. (2024, January 25). Demand Variability. WallStreetMojo. https://www.wallstreetmojo.com/demand-variability/

4. Yoon, D. (2023, August 15). What's the Importance of Technology in Continuous Improvement? KaiNexus.
5. Lathan, N. (2023, March 30). The story of the COVID-19 vaccine, from the lab to millions of arms. Berkley Public Health. https://publichealth.berkeley.edu/covid-19/the-story-of-the-covid-19-vaccine
6. World Bank Group Data. (2023). High Technology Exports (% of Manufactured Exports) - India. World Bank Group. https://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS?locations=IN