

OPERATIONS 4.0

Abstract

Operations in industrial sectors have changed from manual to mechanized to computerized to connected. Designers give a design brief alongside resource constraints to artificial intelligence systems (AI) to begin proceedings. Clay models have given way to rapid prototyping techniques like three dimensional printing. Demand forecasts are becoming accurate and short term. Quality control has emerged from inspection to Japanese quality tools to machine vision and AI. Processing has evolved from assembly lines to kanban control to flexible manufacturing systems. Handling of materials is now being done intelligently using automated guided vehicles, automated storage retrieval systems and robots. E commerce and M commerce have challenged the concept of facility location. Workforce needs no force anymore; instead they have cobots work with. Planning replenishment and forecasts in supply chains have become transparent. Inventory management has become quicker with radio frequency identification tags and drones. Production planning and scheduling have embraced polca card based quick response system, de bottlenecking software like optimized production technology and advance planning and scheduling systems. Maintenance too have become intelligent and preventive with application of AI. This chapter focuses on the recent trends in major decision areas of operations management, in the context of Industry 4.0.

Keywords: Industry 4.0, Operations Management, Mass Production, CPS, Supply Chain Operations.

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I. BACKGROUND

Theme of the Chapter is based on the trends in 10 Decision Areas in Operations Management:

- 1. Design of Goods and Services:** Product Design process includes user research, identifying pain point, ideation for solution, prototype, test & finalises and delivery. Service design means decisions on the set of activities to fulfill customer need. The prominent tools in Product & Service design are Quality Function Deployment and Service Blueprint respectively.
- 2. Managing Quality:** This includes the determination of quality standards, creating and implementing quality tools for compliance, and continuous improvement. Quality of services includes what and how it is being delivered. Japanese philosophies and Gurus are major contributors.
- 3. Process and Capacity Design:** Process design is about designing systems that transform inputs into outputs. Conversion process must produce the product or service at the required rate and quality and at an optimum resources and cost. Capacity planning determines how much capacity is required in order to meet these conversation requirements. The end goal is to have enough capacity in terms of resources to match customer demand.
- 4. Facility Location Strategy:** The ideal geographical region to install a Facility. Facility location has a significant impact on Direct, Indirect, Fixed and Variable costs. Location has become prime factor in deciding the fortunes of many services.
- 5. Facility Layout Strategy:** The basic objective of physical configuration of a facility is to ensure a smooth flow of work, materials, and information through a system. Product, Process, Cellular are prominent among layout choices.
- 6. Human Resources and Job Design:** Motivation of human capital is crucial. Effective job design specifies what the worker does, how, and why.
- 7. Supply Chain Management:** Supply chain management encompasses decisions regarding facility, inventory, transportation, sourcing, information, pricing and their interlinkages. Decisions could tilt supply chain in either responsive or efficient paths.
- 8. Inventory Management:** Inventory management is about how many parts to procure at a time, when to replenish and tools to ensure control. Inventory is locked up capital and has financial implications.
- 9. Scheduling:** A set of decisions regarding which end product and how much to make in a timeframe, the corresponding material requirements, workstation loads, job sequence, time schedules and job instructions.
- 10. Maintenance:** Maintenance is the ensurance of reliability, upkeep of assets and intelligent prevention of downtime.

II. INTRODUCTION

In line with the familiar industrial sarcasm of a dog to guard the factory and a human to feed it, the current reality of Lights Out Manufacturing isn't far away from reality. FANUC can operate in a lights-out way for up to 25 days. Employees shy in for planned routine maintenance or for on-site emergencies only. Where did it all started? In the late 18th century in UK, the first industrial revolution kick started mass production by using water and steam power. A century later, the second industrial revolution with its signature assembly lines came up. Third industrial revolution began in the middle of the 20th century, when computers, advanced telecommunications stepped in. We are now in the fourth industrial revolution alias Industry 4.0 alias smart manufacturing era. The core of Industry 4.0 is cyber physical systems. Cyber-physical systems (CPS) are smart systems that include engineered interacting networks of computational and physical elements. They directly record data using sensors and control physical processes using actuators. They evaluate and record data and actively or proactively interact with the physical and digital world. They are inter connected with each another and in global networks via intangible communication facilities. They use learned and available data and services. They have a series of multimodal human-machine interfaces. CPS has an IP address-assigned to it. CPS has the power of self-monitoring. CPS auto generates information about its own functioning. CPS communicates with other associated entities. The National Institute of Standards and Technology of the USA defines smart manufacturing as fully-integrated, collaborative manufacturing systems that respond live to meet escalating demands and conditions in operations, value chain network, and customer aspirations. Industry 4.0 has re-engineering businesses design, manufacture, and distribution. It aims to have quantum jumps in productivity, efficiency, and flexibility while enabling more intelligent decision-making and customization in manufacturing and supply chain operations.

III. PILLARS OF INDUSTRY 4.0

No wonder, Industry 4.0 is swallowing traditional Manufacturing. Smart factories, the internet of things, robotics, and location tracking technologies, superior human-machine interfaces, rapid prototyping, artificial intelligence, big data, and 3D technologies are reshaping the way that companies make products and the manner in which customers search for, interact with, and shop for pain killers. All of these trends are resulting in the materialization of “Industry 4.0.”

The Pillars of Industry 4.0 could be summarized as follows;

- 1. Big Data and Analytics:** This is deployed for capturing, inventorying, and decoding plethora of manufacturing related input data. The collection and analysis of valuable inputs from data sources like manufacturing equipments , softwares as well as customer interface systems are fast becoming the new tools to support instantaneous decision making. Big data analytics is about ploughing big data to unveil patterns, inter relationships, market trends and customer inclinations.
- 2. Autonomous Robots:** Robots are becoming more fast, flexible, and cooperative. Eventually, they will interact with each other. Modern day cobots work safely side by side with humans. Autonomous robots often have modern attributes which can help them

to understand their physical environment and automate significant portion of their maintenance.

- 3. Simulation:** Simulation allows operators to test in virtual world ahead of the physical making. So material wastage and machine setups aren't required. Ensurance of quality operations in advance was unheard of, before the arrival of simulation. Using mixed-reality simulations with machine learning AI models, it's easier to run simulations. With computer-generated design and development methods, digital transformation has revolutionized design process by eliminating the need to iteratively build physical prototypes.
- 4. Integration of vertical and horizontal nature:** The functional areas, and capabilities of most sophisticated firms will become much more flexible, as inter firm and universal data unification networks are emerging. This enables truly automated supply chains of the future. Horizontal integration points to well-integrated internal processes at the shop floor level. Vertical integration means that the shop floor remains coordinated with higher-level business processes.
- 5. The Industrial Internet of Things:** The industrial internet of things (IIoT) refers to the prudent extension of the internet of things (IoT) in industrial applications. IIoT permits things to convey data and be in touch with both with one another and with its control mechanisms. Individual items can be traced by RFID tags. Work centres or robots learn by self of the processing steps for each item being made. Robots in automotive paint process know the color to perform on the specific work in process.
- 6. Cyber security:** Cyber security is the protection of computers, servers, mobile devices, electronic systems, networks, and confidential information from cyber attacks. With Industry 4.0, the need to protect critical industrial assets and production lines from cyber threats increases multifold. Manufacturing equipment, software systems, data analytics, the cloud, and other connected things need to be safeguarded.
- 7. Cloud computing:** Cloud computing is a virtualization technology that allows us to make, systematize, and customize applications via an internet. Cloud-based systems also make it possible to ensue remote access and monitoring of all valuables and operating systems, providing visibility into operations. With digitalization, more tasks will require unprecedented information related collaboration crossing the internal, external walls of firms. Frontline cloud platforms (AWS, Azure etc) permits processing, warehousing, and analyzing large amounts of data seamlessly.
- 8. Predictive maintenance:** Predictive maintenance is a method that uses data analysis tools to find anomalies in operations and potential defects in machines, so as to fix them before they result in downtime. The world class exemplar, Audi is currently experimenting on flagship projects in the field of smart maintenance in their plant at Neckarsulm. The company relies on big data to forecast as to where, when and which machine are vulnerable to be fail. The aim is to make manufacturing amenities more available and proactively prevent downtime.
- 9. 3D Printing:** 3D printing alternatively known as additive manufacturing is a process of making three dimensional physical objects from a digital file. The process works by

making down thin layers of material in the form of liquid or powdered plastic, metal or cement, and then selectively fusing the layers together. With Industry 4.0, these additive-manufacturing methods have potential to produce small batches of high mix and customized products.

10. Augmented Reality: Unlike virtual reality, which creates its own digital environment, augmented reality adds to the existing reality. Shop floor operators get instructions on how to repair or replace a worn or defective part as they glance through their goggles enabled with AI.

11. Radio Frequency Identification (RFID): RFID systems use radio waves at several different frequencies to transfer information. It is used in tracking items along a supply chain. RFID can help track machinery, inventory in all forms, objects and workers in smart factories.

12. Artificial Intelligence: AI is the development of computer systems capable to perform jobs which normally required human intelligence, such as perception, speech recognition, and translation between languages. AI companies can use the data from a connected factory to optimize operations, manage workflow, and monitor operations to foresee problems and schedule repairs before the failure impacts uptime. Audi makes use of machine learning (ML) for detecting pseudo cracks, which naked eyes could misunderstood as real defects. Software precisely detect the finest cracks in sheet metal parts with unbelievable reliably in split seconds.

Table 1: Technological characteristics of Industry 4.0

1. Connectivity Sensors Internet of Things Cloud technology Blockchain	2. Analytics & Intelligence. Advanced analytics Machine learning Artificial intelligence
3. Human-machine interaction. AR, VR and MR Collaborative robots Robotic Process Automation Chatbots	4. Advanced Engineering. Additive manufacturing Renewable energy Nanoparticles

IV. OVERVIEW OF MANUFACTURING 4.0 TECHNIQUES.

- Machine vision for quality control.
- A R goggles to assist workers.
- Projected SOP (Standard operating procedure).
- AR based training.
- Smart tracking systems.
- Agile war room.
- Digital twin.

- Predictive analytics to optimize machines.
- Wearable for workers.
- 3D printing for production.
- Advanced analytics.
- KPI monitoring using sensors.
- Adaptive control to optimize throughput and flow.

V. DESIGN 4.0

- 1. Bird's eye view of Design process:** Designers search for the customer needs by putting themselves in the shoes of typical users. This is a reframing process of 'point of views from designers' to consumers'. Now, the design team unleashes their creative thoughts and share the design alternatives to the team. Models are built and tested iteratively. The response and emotional underpinnings of a sample customer base are assessed, based on which final design is approved.
- 2. Developments in Product Development:** While many organizations are experimenting in data and design capabilities, only those that closely knit these disciplines will unlock the synergistic benefits. The endeavour of product design is about discovering the longings of target customer group and well thought out arrival at precise solutions. As the world evolves, designing for this planet needs to evolve. Becoming increasingly affordable, 3D printers enable the making of quick and cost friendly physical prototypes of products and ensure more robust end products. By incorporating sustainable design practices and state of the art technology, Tesla creates products that are not only eco friendly but also highly wished for by consumers. Making or printing as close as possible to the place of consumption makes more sense. The distribution and logistics industry may become threatened. Products are becoming smarter. It's time to build bridges between departments and create concurrent teams. Computer aided engineering technology enables the user to virtually model, test, analyze, and optimize alternatives early in the design process by using numerical analysis. Natural language processing and knowledge grounded techniques helps to capture the voice of users and other useful inputs. Augmented and virtual reality help designers visualize offerings at infancy stage of design. Simulation helps to assess potential design options seamlessly. Designers are able to generate path breaking ideas through deep neural networks. All these promises a prosperous future for the domain of design. Generative AI, also known as automated design, is an AI technology that can make designs based on input brief given by designers.

The ability of AI to create more efficient structures means that designers can now land in new possibilities of design that were previously too intricate or time-consuming to go for. For instance, a designer might set resource constraints on the generative AI system to ensure that the product has a certain physique that is in line with the brand's aura. AI fuelled generative design is used to realize highly individualized products or parts for every end-user. Incorporate sustainable design habits into your work, including the use of recyclable materials, energy-efficient manufacturing, and the design of products that are built to be durable. With the advancement of artificial intelligence and robotics, designers have the chance to create products that are smarter and more intuitive, allowing them to respond to changing user preferences. With emergence of AI, AR, VR, and MR, designers have thrilling opportunities ahead. An instance of a synergistic combination

between AI and AR is Animoji of Apple Inc. Meta glass, which superimposes augmented reality on top of our current reality, is predicted to be loved by game designers. Meta glasses uses holographic tools to allow human gestures to manipulate 3D glass projections of connected things. Frame & AR Studio of Face book and AR kit of Apple Inc are also resources of design. Swedish maker, IKEA is developing a smart furniture that logically suggests recipe of your liking based on the materials and spices placed on the table. VR allows designers to preview designs scaled to real world well before even thinking of the shop floor plans. As human eye is good at picking out depth perception, projection of objects is still imperfect. By portraying the interior of a vehicle with a three dimensional camera, firms allows potential buyers of automobiles to see and enjoy minute details before actual purchase. Using Mixed reality (MR) technology, we can simultaneously interact with both digital and physical world. The ideal future is a judicious blend of AI, AR, VR, and MR. Advances in design such as modular components, light weight components, sensors, cameras etc would make the dream of unmanned transit into a reality. The role of the designer shifts from an implementer of tasks to a manager of technology.

3. Design 4.0 Tools.

1. Ideation.
Brainstorming; Mind Mapping; Story Boarding; Brain Writing; Six Thinking Hats; Delphi; Empathy analysis; Personas; Journey Maps.

2. Conceptualization.
Concept Engineering; Kano Model; Morphological Analysis; TRIZ .

3. Embodiment.
Conjoint Analysis; Function Analysis; FAST Method; Reverse Engineering.

4. Design Specs.
Design for functionality; Design for assembly; Design for recycling.

5. Detailed design.
QFD; Taguchi methods; LCA; Kansei Engineering; Neural Networks; Reaction Cards; Emergent emotions.

6. Modeling.
Prototyping; Design for Six Sigma; Design for sustainability; Design for production.

VI. QUALITY 4.0

"Quality 4.0" is a term that points to the future of quality and organizational excellence within the confines of Industry 4.0. It's a new way for professionals to ensure quality using the digital tools and understanding how to deploy them and achieve excellence in quality. Quality professionals must move from data analyzer to wrangler role with able assistance of new technologies, understanding these technologic advances and the potential

solutions they make, and deciding how and when to use them. The fundamentals of Quality would remain the same, but not the means of achieving it.

1. Quality 4.0 tools: Artificial intelligence: Computer vision, Language processing, Chatbots, Personal assistants, Navigation & Cobotics.

- Big data: Machines as data sources, Auto capture tools.
- Block chain: Transparent transactions, Overseeing conditions.
- Deep learning: Image recognition, Pattern classification, Collaborative forecasting, Auto text generation, making fictitious video from real one, editing images based on heuristics.
- Enabling technologies: Cost effective actuators of sensors, Cloud computing, Open software, A R, M R, V R, Data streaming, 5G and IoT.
- Machine learning: Text analysis engines, Recommendation systems, Spam filters, Fraud detection, Classification and grouping.
- Data science: Prediction by decoding heterogeneous data pools. Doing classifications, Pattern identification within large data sets, and Tuning large sets of observations to relevant predictors.

Table 2: Evolution of Quality Management

<p>Quality 1.0 Management of quality meant inspection. Mass production was the priority. Working conditions or HR aspects were not considered. Productivity was the focus. Inspection led to too much scraps, or quality loss.</p>	<p>Quality 2.0 Compliance to standards was the emphasis. Hidden factory, scrap and rework were targeted as evils.</p>
<p>Quality 4.0 Digitization is used to include feedback into design quality. Self learned corrections by machines are being practiced. Quality needs to be built in at design itself. Self managing machines work at their own. Role of knowledge workers is to oversee software run operations by intelligent machines.</p>	<p>Quality 3.0 Meeting customer needs is the goal. Continuous improvement is the way. Highly efficient processes, standardizing of work and employee involvement are paths to quality. Adherence to ISO standards and criteria of quality awards were given emphasis.</p>

2. The keys of Quality 4.0: Connectivity refers to the intertwining of information technology applicable to business and technology relevant to operations. IT includes quality management systems (QMS) of organisation, enterprise resource planning (ERP) software, and product lifecycle management (PLM). Operational technology is the technology used in manufacturing. Relatively inexpensive sensors can sync with connected people, products, edge devices and processes. Quality 4.0 can leverage social listening and block chain to gather customer delighters, and visibility of flows through supply chains. Advanced apps have potential applications in the Quality 4.0 realm. Lack of scalability renders organizations fail to reconcile operations, capabilities and best in class practices. The most effective mechanism which aids in achieving scale is cloud

computing. To realise the benefits of fourth generation quality, organizations should look to utilize software, which will reduce the time management spends on execution. Another advantage is to a revamped focus towards innovation. Success of quality 4.0 depends on a variety of compliance tools and techniques. By linking information, analytics and process steps, gains including visibility, connectivity, teaming up and insights can be arrived at. AR and VR can be used to up skill workers' level and expertise. Wearable can help in employee monitoring. AR and VR can be deployed to deliver one to one training.

3. QC in Action: AI is trained to recognize images of detectives of various nature which are captured by cameras in the recent past.

- Machine vision helps click images of work in process (WIP).
- The AI system compares these live images with pre fed images of faulty & non-faulty parts, thus identifying defective ones.
- The defective parts are isolated instantly from the rest of the inventory and discarded or sent for rework.

Table 3: Quality Management in Information age

1. Customer Focus Smart prediction of market demand. Customized offerings. Improved responsiveness	4. Process approach Visibility of processes. Self-learning machines with early prediction of errors Downtime control.	7. Relationships Stronger collaboration with partners. Segmentation of stakeholders. Easy identification and communication,
2. Leadership Smart resource allocation. Better coordination in the organization Objective evaluation of results	5. Continuous improvement Best re-configuration of production processes. Dynamic interventions in volatile markets. Adaptations to changing environment.	8. Quality assurance Early quality assurance. Early failure detection.
3. Employee engagement. Facilitating ideas and sharing. Improved interactions and collaboration.	6. Objective decisions Analytics and information dashboards. Pre- prediction of failures. Early decision making.	9. Quality control Intelligent control systems. Real-time automated inspections.

Table 4: Focal points of Quality 4.0

1. Data High volume data acquisition of high veracity and visibility.	5. Apps Catered to include suppliers, operations and users.	9. Culture Empowering workers through connected access to establish a culture of quality
2. Analytics Application of big data and intelligence for data analysis.	6. Scalability Cloud-based connected systems.	10. Leadership Executive ownership of quality KPIs.

3. Connectivity Connecting IT and Operations Technology.	7. Systems Connecting automated processes and automating their interlinkages.	11. Competence Prioritize training to practical skill gaps, and hence develop expertise
4. Collaboration Incorporate a block chain including key shareholders	8. Compliance Automated EDM, BPM, data transfer, compliance and liability.	12. Innovation Trust in R & D Open Innovation

VII. MAINTENANCE 4.0

1. Predictive Maintenance: Corrective repairs will progressively come down under Maintenance 4.0. As the cost of sensors are falling, firms are designing smarter assets that can help us better manage the performance and flow of everything from machines on the shop floor, to material handling and robots in the warehouse, to vehicles in logistics and even products at customer premises. “Predicting problems before they occur ” - this puts firm in the position to take quick, preemptive, and budget friendly action to fix them. Leveraging machine learning and predictive analytics, firms can now make recommendations for the machines to comply. By having digital twin of a tangible asset, we can oversee, analyze, optimize and stabilize it throughout its lifecycle from ideation to decommissioning. Benefits of Maintenance 4.0 approach includes minimizing downtime, reduced need for predictive and prescriptive maintenance processes, jump in overall equipment efficiency, increase in useful life of costly equipment and betterment in customer service levels. Big Data technology, alongside A I, allows to determine with the durability of machinery, the probability of failure and the impact on the system. Preventive maintenance is to be carried out intelligently, i.e., the machine is inspected even if there is no sign of degradation. This way, any downtime is averted as much as possible to make sure that the proper running and safety of the assets. Predictive maintenance is rooted on the analysis of data captured using sensors and related technologies, which allow overseeing a set of previously, identified parameters and predict upcoming behaviors. In the maintenance field, the cobots and the inspection drones stand out. With IoT, devices become traceable on the network and can exchange information live. IIoT technology can capture changes and faults that are unnoticeable by the human eye. A prognostic is a discipline which predicts the time at which a system or a component will no longer perform its intended function. Prognostic maintenance uses machine learning, pattern recognition, and neural fuzzy networks. Prescriptive maintenance goes a step further than predictive maintenance because the former evaluates which approach is the fastest or most effective in the given scenario. It tries to answer the question: ‘What should we do to achieve a state of affairs?’. Anyhow, there are several components that must coexist for an industrial asset to be maintained proactively.

Table 5: Cornerstones of Maintenance 4.0.

IOT AND PREDICTIVE ANALYSIS	ROBOTICS AND COBOTICS To perform monotonous	CLOUD MANUFACTURING To produce on-demand
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To predict the likelihood of failure of assets	tasks that have little improvisation	parts and spares for the proper working of assets
DIGITAL TWIN To follow and improve equipment performance	TABLETS / SMARTPHONE To ensure permanent access to timely data	AUGMENTED REALITY To assist and guide technicians during maintenance works

2. Smart AI Maintenance process steps:

- The AI system is trained using data from historical failures of assets.
- Sensors installed in assets collect data on key operational parameters that affect performance.
- This data is fed to data inventory.
- The AI-based system ploughs this data and generates recommendations.
- Notification sent to the relevant personnel, whenever probability of failure rises above a threshold.
- Searching for root cause of breakdown from a large number of likely causes.
- Experiences are fed back into the AI system to enhance its own accuracy.

VIII. SUPPLY CHAIN 4.0

1. Traditional versus Supply Chain 4.0: Supply Chain 4.0 is a combination of practices needed for achieving business success in the age of Industry 4.0.

Table 6: Traditional Supply Chain versus Supply Chain 4.0

Plan and control flows Multiple isolated planning cycles Absence of overall feedback loop Blurred view of total supply chain Compartmental communications Absence of collaboration Too much firefighting Variability among suppliers Imbalance in supply and demand Sizeable inventory Ineffective response Issues in quality, OTD, efficiency Wasted costs and resources	Deming wheel - PDCA Collaborative planning Overall feedback loops 360-degree view of supply chain stages Concurrent. Communications Built-in collaboration Smooth and streamlined operations Harmony between suppliers Balanced supply and. demand Optimal inventory levels On time delivery Increased quality, efficiency Right costs and resources
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2. Supply Chain Advances: Resilience is a covered goal for the lion share of businesses as they come out of the COVID-19 crisis. Brand new approaches of product distribution are being sought to curb the delivery time of products and heavy machinery to a few agile hours. Live planning helps in a flexible response to swinging demand or supply cases. The next generation Supply Chain 4.0 provides live and total transparency throughout the supply chain. Intelligent automation performs the complete warehousing operations – from receipt or unloading to pick, pack, ship, and dispatch of consignments. Optimizing movement adds to agility and efficiency of the movement system. End users are tagged and segregated into small manageable groups. A range of alternative offerings are identified as apt to meet their needs. McKinsey & Company foresees that Supply Chain 4.0 could not only increase agility but also reduces operational expenses by a significant percentage. Design, plan, production, distribution, consumption, inventory, logistics and disposal go through rethinking, using the modernized technologies. The cloud, the internet of things, artificial intelligence, 3D printing, driverless last mile delivery vehicles and drones are pushing the supply chain toward unprecedented transparency, data sharing and predictive analytics. Businesses are moving toward outcome based services, enabled by instantaneous and proactive strategies operating within the cyber realm. The transnational nature of work on the wings of the internet is creating new legal, monetary, ecological and human issues that require novel infrastructures. Supply and demand swings caused by factors such as resource shortages, quality conundrum and uncontrollable happenings are surfacing, putting added pressure on value chains. Forecasts are not done now on a monthly basis, but rather weekly. For the very fast-moving products, it may happen even daily. In the recent future we will witness "predictive shipping," for which Amazon holds a patent. ie, Products are ready to arrive before the customer places an order. Supply chain can be hired as a service or paid for on usage basis rather than investing in the resources and capabilities in-house. Customer orders shall be handled in much more granular clusters and a broad spectrum of options of suited products will be made available. This empowers customers to choose one of multiple "logistics recipes" which exactly matches his or her need. New freight ideas, such as drone delivery allow firms to manage the last mile delivery cost efficiently. The integration of data of vendors, service providers, and other stakeholders in a supply chain cloud ensures that all parties steer in the same direction and decide based on the same true facts. Amazon Kiva robots aids in the warehouse process - from unloading to put away to pick, pack, and ship. This is a complete touch less process, where no manual intervention is required between order acceptance and order realisation. Autonomous trucks transport the items within the guided network. Opportunities arising from new generation devices, such as wearable (e.g., Goggles). Exoskeletons shall also be employed as a human aid. Live replanning enables due date re confirmations to customers. Supply chain clouds are joint supply chain platforms between end users, the firm, and vendors. They provide either a shared logistics platform or joint planning solutions. Capabilities regarding digitization need to be inculcated into the organization. Supply Chain of fourth generation brings in huge pros in terms of inclusive growth, innovation, and entrepreneurial avenues. A core element of Logistics 4.0 is intelligent logistics routing. Technologies are driving the entire value chain ecosystem towards smart warehousing. Smart solutions to encourage agility and enhanced decision making through live course corrections and better visibility into the vendor networks. Cognitive cloud technology enables precise stock replenishment by offering greater visibility of the supply chain operations. To absorb the sense of supply chain 4.0 fully, it is essential for firms to chart out a roadmap that is in line with business goals. The

organisations also need to tackle cyber security risks caused by the array of ecosystem players.

IX. FACILITY MANAGEMENT 4.0

An operations system consists of the plant, machinery and tooling, handling tools, inspection equipment, and computer systems that assist in the manufacturing operations. Cyber physical production systems (CPPS) comprise intelligent equipments, distribution centre systems, and shopfloor facilities that have been set digitally. The control of activities from inbound logistics to intra to outbound logistics, marketing till after sale services is to be done. Facility Management is a coalesced approach of running, status quo, bettering and adapting the facilities and infrastructure of a firm in order to create an environment that supports the vision of that firm.

1. Factory Design: The future of factory design brings with it opportunities and challenges. Factory layout is one of the key foundations of factory design and deals with solving increasingly intricate problems in an ever shorter timeframe. Softwares, architects, manufacturing and maintenance engineers, IT people, logistics and materials handling experts often come into action. In sum, this involves a design that explains and depicts the spatial configuration of factory equipment such as conveyors, packaging systems, storage facilities and other machinery. With a 2D layout, each orthogonal and sectional view has to be prepared manually, but with a 3D layout, changes can be effected with just clicks, and all required perspectives are then generated automatically. The high veracity of today's computing systems and the use of powerful 3D software make 3D layouts a far more adoptable proposition. CAD systems such as M4 PLANT enable the digital representation of entire plant in 3D. 2D pictures such as building floor plans can be imported and used as the input for the 3D design. 3D terrain model makes it a reality to make decisions viz calculation of the volume of soil that will need to be excavated for the factory foundations and so forth. 2D drawings with elevation and sectional views can be automatically made from the 3D model. The building and layout modules can be augmented with extra modules ranging from 3D pipe work design, to ducting layout and much more. For instance, it is easy to route entire conveyor pathway - thanks to its Mechanical Handling module. Another instance may be ducting module where ducting, reducers, exhaust and many other types of ducting component can be selected from the supplied options to create heating, AC and ventilation systems in 3D. An electrical design module enables the catalogue-driven design of cable tray and ladder networks. Advanced Collision detection module enables problems to be foreseen early and remedied an infancy stage. The ability to use 3D visualization for design reviews and presentations is provided for by another module. Once the wished for extensions and alterations are finished and the factory is rearing to go.

Virtual Reality for Factory Layout:
In VR everything you see is digital. That's the benefit of VR over CAD. All data, work cell, work station & the complete factory at full scale could be walked around and experienced.

Table 7: Elements of Warehousing 4.0

Command Centre & Digital twin	AGV
Picking using Augmented Reality	Smart conveyance between stations
Cycle counting without human touch	ASRS
Smart receipt of materials	Automated air tight packing
In-house 5G network	Robotic handling

2. Advances in Facility Management: CBRE research shows that eight seven percent of big corporations are adopting a hybrid strategy wherein employees work remotely at least some fraction of the time. Facility managers need to rethink the practical requirements for office space. It seems better to open more sites, such as satellite offices in suburbs which are closer to where people dwell. The central office remains the hub for team gelling, training, and coaching that support a unified company culture. Co-working spaces can serve as spokes which aid people connect in mini groups between home and office. Hot desking permits employees to take any free space. Hoteling offers assurance by requiring reservations. Employees can make bookings as and when required, which may be once a week, month, or other intervals. So, workplace leaders need to keep a hospitality mindset and think about the technology, services, and amenities each person needs to perform to their level best. The internet of things with its innovative ways creates optimized building management in many areas. Smart building stands for the automation and central operation of technical tools in offices, logistics centres , shopping hubs or shop floor. Intelligent building helps facility managers establish a more habitable, energy saving arrangement. Using Artificial intelligence to monitor assets and amass data makes it easier for managers to predict the optimum lifecycle of capital investments before their performance degrades or before the asset breaks. Building information modeling software maps any tangible asset all through its functional lifecycle, from cradle to grave. Instead of conversing to their colleagues on a 2 D screen, employees could interact with 3 D avatars in shared spaces that exactly resemble the actual office settings. They could hold hands with haptic feel or tour the facility with a VR headset that gives them an audiovisual experience.

Space planning tools like Space Right can assist in configuring office spaces for safety or plan for unreal scenarios. More offices are adopting wifi enabled smart lighting. HVAC systems that adjust itself based on number of incumbents, and touch less visitor management systems that permit guests to register in advance or scan a QR code when they arrive are becoming common. Intelligent heating, cooling, and safety allow facilities managers to be responsive and efficient at the same time. Adopting sustainable facilities management practices is a priority for many firms. Some applications can make virtual meetings more lively by creating holograms of participants. The leapfrog of technology has not only changed the way firms conduct businesses, but it has also altered the way they opt where to do business from. Digitalization, automation, and connectivity are reframing the manufacturing landscape. So, plant layout needs to align with the sustainable development goals of United Nations. Lean layout can eliminate unwanted bodily movements, avoidable transportation, and queue times. A modular layout can allow

for quick reconfiguration and customization. A smart layout can leverage sensors, analytics, and AI to monitor and improve the performance level, quality standards, and life of the equipments. A green layout incorporates renewable sources, natural ventilation and cooling. A circular layout can facilitate the reuse, recycling, recovery of items, and the prevention and reduction of muda. A human-centered layout can provide just enough disturbances and noises for the workers. A collaborative layout can enable the interaction and co-working between humans and robots, as well as between different teams and functional areas. A compliant layout respects the relevant norms and policies, the privacy of the data, workers and customers. A learning layout can facilitate by open feedback, evaluation, and experimentation of the processes and results. Small batch or high mix/low volume manufacturing continues to grow and is enabled by advances in machining, design and management. By classifying parts into families based on similarities, the Group technology approach provides manufacturers with a fruitful way to manage the challenges of the fourth industrial era. Smart warehouses entail a series of self aware functionalities that work hand in hand to improve inventory efficiency, equipment productivity. Human errors are also reduced. For example, unloading by automated guided vehicles, automated vertical storage, and order picking of robots are all managed by the latest software solutions.

X. WORKFORCE 4.0

- 1. Advancements in Human Capital Management:** HR leaders are increasingly focusing on reskilling and up skilling their workforce to ensure competency development. Employees wish for more personalized experiences at workplace, and prefer to be part of organizations that place emphasis on employee engagement, and career development. There is a need to reimagining the way companies approach employee involvement strategy. The HR function will have to proactively take up measures to develop and nurture a culture of agile, digitally-savvy, self-directed, and customized learning. ISO has issued new reporting standards such as ethics, diversity, leadership, inclusive culture and employee wellness, talents management, and succession planning. Focus shall be on directing behaviors, attitudes, and mindsets. New ways of on boarding skilled workers, adopting HR technologies, and working closely with employees on a nurturing basis are required. One of the key features of HR 4.0 must be the redefined mutually beneficial relationship between the employer and management. Production firms must develop empathy and proactively ask feedback and input from employees, and work with them during this technological age. It is generally assumed that, because equipment and operations are increasingly automated and intelligent, human labor may no longer be needed. But, not necessarily. See the new job on offer - Digital twin Engineer. A digital twin engineer makes it possible to virtually see inside any physical asset, system, or structure to optimize design, monitor performance, predict maintenance, and improve the overall experience. Since the digital thing, no matter how secure, involves the possibility of cyber threats and information leakage, it is also necessary to hire specialists in that area. Behind the algorithms that make up digitalized manufacturing, there are IT professionals. In this context, investing in knowledge workers is important. Emphasis shall be on quality rather than cost of recruitment. This approach helps organizations identify high-potential workers with elusive technical skills. Leaders attribute shortage of talent as the top barrier in realising their digital plans. A transformation program, prepared by top management with involvement of the experienced workforce is to be thought of. Companies must tailor their training and development to match both the mission of the firm and the

aspirations of individuals. Other than making use of technical content, successful reskilling programs are too required.

2. Skilling and Reskilling Process Map: A Corporate hub shall sponsor the imparting of reskilling programs. Learning journey is outlined below:

- Companies must assess the nature, quality and quantum of futuristic skills available as of baseline time.
- Analyze the shortages in skills required to deliver on their strategic goals and ambitions of workforce.
- Identify the underlying forces that can make or break a reskilling program.
- Develop a robust strategy to fill these gaps or opportunities. ie, a right skilling strategy with associated tactics shall be in place.
- Get the wholehearted willingness of its people towards embracing change.
- Prioritize the skills that has potential to upgrade the largest number of people.
- Plan for the shift in skills of key roles.
- Develop quality content.
- Device user friendly delivery mechanisms for each of its priority modules.
- Involvement tactics like gamification approach shall be used to train people in the digitally enabled working ways.
- Give selective access to a database of add-on online apps in which they complement learning.
- High performers shall receive both recognition and reward.
- Assess the impact of the initiative using right matrices.
- Use agile techniques to adapt and refine learning systems.

3. The Smart blend of HR 4.0: The goal of HR 4.0 leadership shall be to ensure right mix of the five taxonomies of modern workforce in the right proportions at any point of time.

Table 8: Workforce Mix

1.Soft workforce Flexible & Socially Intelligent	2. Hard workforce Professional & Dexterous
3. Cognitive workforce Intelligent & Analytical	4.Emotional Intelligent workforce Neurotic controlled & Empathetic
5. Digital workforce Digitally literate & interactive	

Automation and robotics aren't about replacing the workforce, but instead, enhancing it, providing work, life and business benefits to all involved.

XI.INVENTORY 4.0

1. Lean Inventory: Efficient and effective management of inventory is a challenge for all manufacturing sectors and companies. Inventory shall be embedded with the data on their locations and monetary values. Based on real time information inventory systems are able to automatically trigger the more orders with the right quantity at the re order time.

Systems shall be able to foresee when to order and how much quantity to place order with. Variability in lead times shall be tackled by live information sharing of all the parties and entities. Inventory of fourth generation allows firms to start using the continuous review system (Q system), than a conservative periodic system. The inventory policy is dictated by solving an optimization problem composing of an objective function and select constraints. The problem is formulated based on the assumption on the requisite parameters. Using deep data analytics, the best inventory policy is expected to be arrived at. Key matrices include quality, delivery, price, responsiveness and agility. Cameras or sensors are supposed to be able to automatically identify danger levels and place fresh orders by themselves. Smart factory will have limited storage capacities and inventory of the size of reorder level (RoL). Ideal order sizes are smaller, with frequent replenishments. Automated guided vehicles (AGV), Automated storage and retrieval systems (ASRS) and automated mobile robots (AMR) are tools to manage warehouse inventory. Machine learning could be employed to detect defects in finished products or packaging to ensure that users get quality items. A GPS location system shall be in place. You track skids in transit, containers or despatch vehicles live. Cloud based software permits granular tracking of inventory down to the SKU or RFID or barcode level. Keeping inventory across multiple distribution centres can curtail movement related costs and speed up delivery. Picking software of predictive nature can direct businesses to initiate fulfillments before an order has even been thought of by customer. A robust inventory system allows companies to tap into individual consumer behaviour and use it to boost revenue. Firms with stock that's nonmoving may also take measures to aid liquidity. Converting stale stock to cash by offering appealing offers or bundling nonmoving items with best sellers are some measures to take up. SKU mapping, order fulfillment, live shipping rates and notifications for reorder are part of modern inventory management. Advanced warehouse automation could use AI to assist a smart device navigate through warehouse and compile an order without human involvement. The key to success is to connect all production sites, including the manufacturer and third party contractors, such that they work as a cohesive supply chain. We've witnessed retailers shake hands with 3PL to store revolving inventory and deliver orders directly to end customers. Omnichannel strategy requires coordination among stores, distribution centers and ecommerce operators. The task is to reconcile physical and online inventory and ensure right price and price offers.

2. Contemporary challenges of inventory management systems:

- Coordination in restocking in multiple vendor setting with stochastic demand
- Optimizing dynamic inventory restocking and substitution for parts with long lead times
- Inventory Control in scenarios with random yield
- Transshipment management of manufacturing facilities
- Inventory Control for perishables with random offers.
- Rationing for systems with multiple demand classes
- Ordering Policies with unreliable vendors and counterfeit parts
- Replenishment by way of flexible contracts in spot market
- Inventory pooling techniques in case of information asymmetry

XII. PLANNING & SCHEDULING IN INDUSTRY 4.0.

- 1. De-congestion Management:** In the foregone years of manufacturing, scheduling was a simple process of deciding what needs to be made and allocating workers to do the task. Gantt charts were utilized to schedule and check the progress of tasks. Critical path method narrows down a project into simpler tasks and determined the sequence in which jobs needed to be done. Assembly line balancing means dividing an assembly line into workstations and assigning jobs to each work centre. Kanban is the use of cards to control the flow of parts and information between the work stages. Materials requirement planning (MRP) used inputs like orders received, status of stock, and free capacity to create a workable schedule. Dynamic scheduling rely on data amassment using sensors, ERP systems, and production machines and live decision making. This allows makers to respond to alterations in production scenarios as and when they surface. Sensors follow the status of machinery, track stock, measure performance, and spot constraints or issues that necessitate attention. Data is analyzed to generate insights that could be triggered to optimize making. Capacity planning algorithms streamline schedules based on available supply, demand, and other constrained resources. Hence manufacturers can control downtime, enhance the utilization rate of machinery, and ensure the overall efficiency. So, orders are done before due dates in accordance with quality standards. Algorithms can help manufacturers identify idled resources, reduce wastages, and allocate resources optimally. APS software provides a platform for managing shop floor information, scheduling, and other work related assignments. APS can integrate with complementary softwares like ERP and MES. APS enables makers to take learned decisions about resource allocation and workflows. As a result, manufacturers achieve visibility into their value chain. It has the capability to analyze what-if scenarios, allowing makers to simulate different templates. The benefits include greater efficiency, shrunked costs, and user delight. Recently, advanced scheduling techniques such as Finite capacity scheduling, Theory of onstraints or OPT, and Quick response manufacturing have come into the foray. Machine learning algorithms can be deployed to optimize production plan. Machine learning models can decide on precise schedules that attacks downtime and maximize flow. Manufacturers can cut waste and downtime. This adds to efficiency by using algorithms which optimize schedules based on critically constrained bottlenecks. Finite capacity scheduling takes into account the capacity of resources such as machines, labor, and materials. TOC scheduling uses OPT algorithm to identify bottlenecks and optimize flow. Critical chain scheduling does scheduling by revolving around critical tasks. Hence, manufacturers can ensure efficiency and reduce the fear of tardiness. Agile scheduling breaks operations into manageable sub tasks, makers can respond fast to peaks or valleys in orders. Machine learning algorithms can zip through large inflow of data to predict outcomes, such as how long a specific bottleneck process will last. Microsoft Teams, Asana and Slack are handy collaboration platforms. Information sharing tools like Tableau and Power BI are user friendly digital dashboards. Conferencing tools like Zoom have become routine for remote assistance in recent years. Data analytics plays a pivotal role in the resurgence of a scheduling systems.
- 2. Role of Industry 4.0 tools in the revamp of PPC:** Algorithms & Data Models: The problems of scope, complexity, and replanning can be addressed.

- Artificial Intelligence: Live response to changes in plans and schedules, along with its unaided implementation.
- Internet of Things: Helps provide timely information on the status of the plant operations as well as the value chain.
- Analytics: Provides useful insights needed to generate and change plans and schedules.
- Digital Twin: A digital twin models reality before it happens on the floor.
- Cloud: Budget friendly on - demand is made possible.
- Cyber physical platforms: Helps users to resolve the delicacies of planning and scheduling problems.
- Digital Supply Chain Management: Allows for a multi echelon approach towards the seamless supply chain.
- Block chain: Safe and private communication between autonomous things.
- Mobility: Mobile phones bring the power of fourth generation scheduling to relevant users wherever they might be located.

XIII.SMART PROCESS TECHNOLOGIES.

A central platform for management of data is essential and developed according to use case. The enablers are IoT devices, enterprise apps and MES. Data management foundation includes four components viz data acquisition, data management & storage, data processing, generation of insights and automatic execution of decisions.

Table 9: Material Processing Technologies

1. Industrial Robots	2. FMS - Flexible Manufacturing System
3. Process Control	4.CNC Machine tools
5. AGV - Automated Guided Vehicle	6. CIM - Computer Integrated Manufacturing
7. ASRS - Automated Storage and Retrieval	

Table 10: Information Processing Technologies

1. Internet	2. DSS - Decision Support System
3. Radio frequency identification	4. Extranet with Suppliers
5. ES - Expert System	

Table 11: Product Technologies

1. PLM - Product Lifecycle Management	2. GT - Group Technology
3. CAE - Computer Aided Engineering	4. CPC - Collaborative Product Commerce
5. PDM - Product Data Management	

Table 12: Process Technologies

1. CAPP - Computer Aided Process Planning	2. CAD/CAM - Computer aided Design & Manufacture
3. STEP - Standard for Exchange of Product Model Data	

XIV. CONCLUSION

The original industrial revolution was marked by a transition from manly production methods to machines powered by vaporized water. The Second industrial revolution happened with invention of electricity. A transformation of factories into modern assembly lines with high utilization and a spurt in revenue. The Third industrial revolution started with computers. This lead to unaided making. The concept of Industry 4.0, a brainchild from Germany, has become a internationally adopted term in this era. We are currently thriving in the fourth industrial revolution, which is based on the concept of digitalization encompassed by automation, artificial intelligence, connected devices, data analytics, cyber-physical systems, digital transformation, and more. This chapter looked at how Industry 4.0 has and is impacting the 10 strategic decision areas of operations management. The five summarizing points of Industry 4.0 are Focus on equipment connectivity, mass personalization, smart supply Chain, smart products and remote workforce. From an operations practitioner perspective, intelligent maintenance and product quality inspection hold the key. We are now entering the fifth industrial revolution with a focus on man and machines working together. Industry 4.0 is considered to be technology-driven, whereas Industry 5.0 is value-driven. The co-existence of two Industrial Revolutions is happening now in developed industrial nations. With all said, a word of caution! With just 22 words, the statement by AI proponents themselves in 2023 read, "Mitigating the risk of extinction from AI should be a global priority alongside other societal scale risks such as pandemics and nuclear war." There are huge upsides to AI if we can control it. The hanging sword applies to all aspects of Operations 4.0 discussed in this chapter. Hopefully, Industry 5.0 addresses and evaporates concerns.

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