Operations 4.0

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**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

**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.

**I. Introduction to Chapter.**

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 kickstarted 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 phsical 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.

**II. 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 technology is used for continuous capturing, storing, and decode large volume of production-related data. In an Industry 4.0 context, the collection cum evaluation of data from many different sources—manufacturing equipment and systems as well as customer-management systems—will become norm to support real-time decision making. Big data analytics is about examining big data to uncover patterns, correlations, market trends and customer preferences.

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 before the physical changeover, thereby driving down machine changeover times and enhancing quality. 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.

With Industry 4.0, firms, functional areas, and capabilities will become much more flexible, as inter firm and universal data-integration networks emerge, thereby enabling truly automated supply chains. 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 allows things to communicate and interact both with one another and with centralized control systems. Products are identified by radio frequency identification tags, and workstations or robots auto learn which manufacturing steps must be performed for each product. 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 Industry 4.0, more operations-related tasks will require unprecedented data sharing across platforms and company walls. Frontline cloud platforms (e.g., AWS, Azure) 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. Audi is currently testing this flagship project in the field of smart and digital maintenance at the Neckarsulm plant. The company utilities big data to probe when and which machine are likely to be down. The aim is to maintain manufacturing amenities more efficiently and 0 downtime.

9. 3 D 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. Workers may receive repair instructions on how to replace a particular part as they are looking at the actual system needing repair. This information may be displayed directly in workers’ field of sight using devices such as augmented-reality glasses.

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 is one of the first car manufacturers in the world that will use machine learning (ML) in series production in future - for pseudo crack detection, which humans are prone to. As regards precision, software detects the finest cracks in sheet metal parts - automatically, reliably and in a matter of nano seconds.

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| **Table 1 : Technological characteristics of Industry 4.0**  |
| 1. ConnectivitySensorsInternet of Things Cloud technologyBlockchain | 2. Analytics & Intelligence.Advanced analytics Machine learning Artificial intelligence |
| 3. Human-machine interaction.AR, VR and MRCollaborative robotsRobotic Process Automation Chatbots | 4. Advanced Engineering.Additive manufacturingRenewable energy Nanoparticles |

**III. 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.

**IV. Design 4.0**

1. Bird's eye view of Design process.

Designers identify what the customer and place themselves in the end-users' shoes — to reframe their point-of-view in tune with that of the consumer. Next is a teamwork stage, where the design team unleash their creative side and share their ideas and design possibilities and feasible solutions. Prototypes are built for different solutions and tested on real users — to find out their reactions and feelings, based on which prototype can be tweaked to create the final product.

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 process of product design is all about defining problems of target group and coming up with precise solutions that can help us create usable antidote. 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. Powered by 3D printing, making or printing as close as possible to the place of consumption makes more sense, beware - distribution industry may become extinct. 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. These days we use advanced natural language processing (NLP) and knowledge based techniques to get customer voice and inputs which are highly relevant for the design process. Technologies such as Augmented and Virtual Reality (VR) help designers visualize physical products at infancy stage of the design process. In addition, simulation and analysis platforms help them to assess potential designs seamlessly. Designers are able to generate new ideas through deep neural networks which promise to a bright future of product 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-driven generative design can be used to create highly individualized products or parts for every customer. 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. By leveraging new and upcoming technologies like AI, AR, VR, and MR, designers have fresh and exciting opportunities ahead in designing market offerings. A great example of a perfect combination between AI and AR is with Apple’s Animoji, an animated emoji mix for the iPhone X. A product like Meta glass, which overlays augmented reality on top of the reality, is likely to be loved as a medium for game designers. Based on holographic technology, Meta glasses can identify human gestures to let them manipulate 3D projections of things. Some laudable augmented reality design and development resources are Face book Frame & AR Studio and Apple AR kit. IKEA is developing a smart table that suggests recipe based on the raw materials placed on it. This is a great example of AR technology working in the everyday life. With VR, designers will be able to preview designs scaled to real environments and before even thinking of the production plan. But, since the eye is very good at picking out depth perception, projection of objects by designers needs to be detailed. By portraying the full interior of the vehicle with a Three-D camera, Audi allows customers see minute details before launch. Using the Mixed reality (MR) technology, we can interact with both digital and world as well as interact with 3D holographic projections. The Future Is a right mix of AI, AR, VR, and MR. The future may be termed as hyper reality—a blend of AI, AR, VR and MR. Design advances such as modular, detachable buses, flying taxis, and suspended magnetic pods will make the dream of unmanned transit world into a reality. Mobile app designers will shortly be making augmented applications that intertwine with physical spaces to deliver exciting way of interacting with our physical realm. The role of the designer shifts from an implementer of tasks to a manager of the new age technology.

3. Design 4.0 Tools.

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

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

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

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

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

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

**V. 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, Chat bots, Personal assistants, Navigation, Robotics.

Big data: Infrastructure, access to data sources, tools for managing large data pools without having to use supercomputers.

Block chain: Increasing transparency of transactions, monitoring conditions, so that transactions don’t occur unless quality objectives are satisfied.

Deep learning: Image classification, Pattern recognition, Collaborative forecasting, Text generation, making fictitious video from real one, editing images based on heuristics.

Enabling technologies: Cost effective sensors and actuators, Cloud computing, Open software, augmented reality, Mixed reality, Virtual reality, Data streaming, 5G networks, and IoT.

Machine learning: Text analysis, Recommendation engines, Spam filters, Fraud detection, Classifying things into groups.

Data science: The practice of bringing together heterogeneous data pools for making predictions, Performing classifications, Identifying patterns in large data sets, and Limiting large sets of observations to most relevant predictors.

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| **Table 2 : Evolution of Quality Management**  |
| Quality 1.0Quality is assured through inspection. Production volume is priority rather than quality. Inspection does not focus on cost cutting, eradicating wastes, or loss and inefficiencies. Work conditions are not considered; maximizing worker productivity takes the main stage. | Quality 2.0Maximizing productivity remained to be the primary focus. Adherence to standards that reflect the just about acceptable quality level is prevalent. Financial quality is measured based on volume of process wastage, scrap and rework.  |
| Quality 4.0Digitization is used to streamline feedback and process set-up. Self Learning supports self induced corrections..Quality shifts its focus from the process conductors to the designers. Machines learn to self-regulate and manage at their own. Human performance is essential; the emphasis shifts from production to system design and integration with the business system. | Quality 3.0Meeting 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. |

2. The keys of Quality 4.0

In terms of Quality 4.0, connectivity refers to the connection between information technology applicable to business and technology relevant to operations. IT refers to tools such as quality management systems of organisation, enterprise resource planning software, and product lifecycle management. 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 considerable potential in the Quality 4.0 realm. Lack of scalability renders organizations fail to reconcile processes, competencies and best in class practices. The principal Industry 4.0 tools that aid in achieving scalability is cloud computing. To fully reap the benefits of Quality 4.0, organizations should look to utilize software, which will reduce the time management spends on execution. Another advantage is to allow them to shift focus toward innovation. Quality 4.0 provides a variety of compliance tools and techniques. By connecting data, analytics and processes, gains viz visibility, connectivity, collaboration and insights can be achieved. AR and VR systems can be used to up skill workers’ expertise. Wearable can help in employee appraisal. AR and VR can be deployed to initiate training delivery.

QC in Action:

AI system is trained to recognize images of detectives of various types captured by cameras in the past.

Camera-based machine vision system clicks images of work in process.

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.

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| **Table 3: Quality Management in Information age.**  |
| 1. Customer Focus Smart prediction of market demand.Customized offerings.Improved responsiveness | 4. Process approachVisibility of processes.Self-learning machines with early prediction of errorsDowntime control. | 7. Relationships Stronger collaboration with partners.Segmentation of stakeholders.Easy identification and communication, |
| 2. LeadershipSmart resource allocation.Better coordination in the organizationObjective evaluation of results | 5. Continuous improvementBest re-configuration of production processes.Dynamic interventions in volatile markets.Adaptations to changing environment. | 8. Quality assuranceEarly quality assurance.Early failure detection. |
| 3. Employee engagement.Facilitating ideas and sharing. Improved interactions and collaboration. | 6. Objective decisionsAnalytics and information dashboards.Pre- prediction of failures.Early decision making. | 9. Quality controlIntelligent control systems.Real-time automated inspections. |

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| **Table 4 : Focal points of Quality 4.0** |
| 1. DataHigh volume data acquisition of high veracity and visibility. | 5. AppsCatered to include suppliers, operations and users. | 9. CultureEmpowering workers through connected access to establish a culture of quality |
| 2. Analytics Application of big data and intelligence for data analysis. | 6. ScalabilityCloud-based connected systems. | 10. LeadershipExecutive ownership of quality KPIs. |
| 3. ConnectivityConnecting IT and Operations Technology. | 7. SystemsConnecting automated processes and automating their interlinkages. | 11. CompetencePrioritize training to practical skill gaps, and hence develop expertise |
| 4. CollaborationIncorporate a block chain including key shareholders | 8. ComplianceAutomated EDM, BPM, data transfer, compliance and liability. | 12. InnovationTrust in R & DOpen Innovation  |

**VI. 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.

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| **Table 5: Cornerstones of Maintenance 4.0.** |
| IOT AND PREDICTIVE ANALYSIS To predict the likelihood of failure of assets  | ROBOTICS AND COBOTICSTo perform monotonous tasks that have little improvisation  | CLOUD MANUFACTURINGTo produce on-demand parts and spares for the proper working of assets |
| DIGITAL TWINTo follow and improve equipment performance | TABLETS / SMARTPHONE To ensure permanent access to timely data | AUGMENTED REALITYTo assist and guide technicians during maintenance works |

2. Smart AI Maintenance process steps:

a. The Al system is trained using data from historical failures of assets.

b. Sensors of assets continuously collect data on operational parameters that affect performance.

c. This data is fed to data storage.

d. The Al-based system analyzes this data and makes recommendations.

e. Notifies the relevant personnel, when fault probability rises over a threshold.

f. Identifying root cause of breakdown out of a large number of possible causes.

g. Experiences from failures is fed back into the Al system to improve its own accuracy.

**VII. 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.

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| **Table 6 : Traditional Supply Chain versus Supply Chain 4.0** |
| Plan and control flowsMultiple isolated planning cyclesAbsence of overall feedback loopBlurred view of total supply chainCompartmental communicationsAbsence of collaborationToo much firefightingVariability among suppliers Imbalance in supply and demand Sizeable inventory Ineffective response Issues in quality, OTD, efficiencyWasted costs and resources  | Deming wheel - PDCACollaborative planning Overall feedback loops360-degree view of supply chain stagesConcurrent.communicationsBuilt-in collaborationSmooth and streamlined operationsHarmony between suppliersBalanced supply and. demandOptimal inventory levels On time delivery Increased quality, efficiencyRight costs and resources |

2. Supply Chain Advances.

Improving resilience is a goal now for the lion share of businesses as they come up from the COVID-19 crisis. Brand new approaches of product distribution cut down the delivery time of the high performers and heavy machinery by a few agile hours. Real-time planning helps in a flexible response to changing demand or supply scenarios. The next generation Supply Chain 4.0 provides real-time, end-to-end transparency throughout the entire supply chain. Intelligent automation does the complete warehousing operations – from receipt or unloading to pick, pack, ship, and dispatching consignments. Optimizing transports add to flexibility and efficiency of the entire transport system. Customers are identified and segregated into small groups. A range of offerings are identified as apt to meet their needs, McKinsey & Company foresees that Supply Chain 4.0 could not only increase supply chain agility but also reduce operational costs by a significant %. Design, plan, production, distribution, usage, inventory, and logistics go through a re-engineering, using the modernized Industry 4.0 technologies. Emerging technologies such as the cloud, the internet of things, artificial intelligence, 3D printing, robotics, driverless last mile vehicles, drones, and augmented and virtual reality are pushing the supply chain toward unprecedented transparency, real-time data sharing and predictive analytics. Businesses are moving toward service-based outcomes, enabled by real-time and proactive strategies operating within the cyber realm. The international nature of work, on the wings of the internet, is creating new regulatory, financial, ecological and people issues that require novel infrastructures and networks. Supply and demand variations caused by factors such as raw materials and resource shortages, quality conundrum and natural happenings are becoming extreme, putting additional pressure on value chains. The combo of AI and ML defines the kind of model necessary for precision in forecasting. Forecasts are not done on a monthly basis, but weekly, and for the very fast-moving products even daily. In the near future we will see "predictive shipping," for which Amazon holds a patent - products are ready to arrive before the customer places an order. Supply chain can be purchased as a service and paid for on usage basis rather than investing in the resources and capabilities in-house. Customer orders shall be dealt with in much more granular clusters and a broad spectrum of suited products will be made available. This empowers customers to choose one of multiple "logistics recipes" that exactly matches their need. New transport 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 and decide based on the same facts. Amazon Kiva robots aids in the warehouse process - from unloading to put away to pick, pack, and ship. The goal is to have a complete touch less process, where no manual intervention is required between order acceptance and order realisation. Autonomous trucks transport the items within the network. Opportunities arising from new generation devices, such as wearable (e.g., Goggles) or exoskeletons shall also be employed. Real-time replanning enables due date confirmations through instantaneous, in-memory replanning of the production plan and the replenishment in consideration of all limitations. Supply chain clouds are joint supply chain platforms between end users, the firm, and vendors, providing either a shared logistics platform or even joint planning solutions. Capabilities regarding digitization need to be inculcated into the organization. Supply Chain 4.0 brings in huge pros in terms of inclusive growth, innovation, and entrepreneurial avenues. Deployments, frameworks, analytics, software ecosystems, out of control realities, and other unforeseen aspects need to be aligned to Industry 4.0. Block chain technology, AI, and the Internet of Things are identified by all the major world class exemplars to automate supply chain management and logistics routing. A core component of Logistics 4.0, an extended arm of Supply Chain 4.0 is intelligent logistics routing. Artificial intelligence, internet of things, predictive analytics, augmented reality, computer vision, big data, robotic process automation, and digital twins are driving the entire value chain ecosystem towards smart warehousing. AI-driven smart solutions to encourage agility and enhanced decision-making through real time course corrections and better visibility into the vendor networks. Cognitive Cloud technology enables precise stock replenishment decisions by offering increased visibility of the entire supply chain operations. Therefore, to absorb Supply Chain 4.0 it is essential for firms to create a roadmap that is in line with business goals. The organisations also need to handle cyber security risks caused by the array of supply chain technologies and ecosystem players.

**XIII. Facility Management 4.0**

A production system is the one whose facilities consist of the factory, machines and tooling, handling equipment, inspection equipment, and computer systems that do the manufacturing operations. Cyber-Physical Production Systems (CPPS) comprise smart equipment, warehousing systems, and manufacturing facilities that have been set digitally and feature end-to-end IT integration, from inbound logistics to intra to outbound logistics, marketing, and services. Facility Management is an coalesced approach of operating, maintaining, bettering and adapting the facilities and infrastructure of a firm in order to create an environment that supports the objectives 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.

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| 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.  |

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| **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 87% of large corporations are adopting a hybrid strategy where employees work remotely at least a portion of the time. This means facilities managers need to rethink how much office space they practically need. It seems better to open more locations, such as satellite offices in suburbs that are closer to where people live to encourage more face to face deliberations. The central office remains the “hub” for team gelling activities, training, coaching and mentorship that support a unified company culture, while co working spaces can serve as “spokes” that aid employees connect in mini groups between home and the office. While hot desking permits employees to take any available seat, hoteling offers more certainty by requiring exact reservations. Employees can make reservations as and when needed, which may be a few times a week, month, or other intervals. To keep up with this upcoming facilities management method, workplace leaders need to practice a hospitality mindset and think about how they can provide the technology, services, and amenities each person needs to do their level best. The internet of things with its innovative technologies creates optimized, intelligent building management in many required areas. The term smart building stands for the automation and central operation of technical tools in, for example, offices, logistics hubs, shopping centers or production floor. Additionally, intelligent building technology helps facility managers establish a more habitable, energy-efficient atmospherics, manage facility and assets, and plan for future needs of the man made environment. Using Artificial intelligence to monitor physical assets and amass data makes it easier for facility managers to predict the optimum lifecycle of capital investments before their performance gets affected or before the asset breaks. Building information modeling software maps any tangible asset throughout its functional lifecycle, from design to grave. In the workplace, smart building technology is already helping facilities managers create a more comfortable, energy friendly environment, manage building systems and assets, and plan for future requirements. Instead of talking to their colleagues on a 2 D screen, employees could interact with 3 D avatars in shared spaces that exactly resemble the physical office. They could shake hands with haptic feel or tour a facility with a VR headset that gives them an audio-visual experience. Strategic space planning tools like Space Right can assist you in adjusting office spaces for safety or plan for unreal scenarios. We can see more offices adopting touch less, sensor enabled tools like smart lighting, HVAC systems that adjust 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 instead of waiting. New HVAC technology powered by the Internet of things is making it easier than ever to curb energy requirements while improving the workplace comfort. Smart building elements, such as intelligent lighting, heating, cooling, and safety, allow facilities managers to be simultaneously responsive and efficient. Adopting sustainable facilities management practices is a contemporary priority for many firms. Modern facilities management technologies offer some applications, such as making virtual meetings more lively by creating holograms of participants. The leapfrog of technology has not only changed the way firms conduct business — it also has altered the way they choose where to do business from. In the era of Industry 4.0, where digitalization, automation, and connectivity are reframing the manufacturing landscape, plant layout needs to align with the sustainable development goals of UN. Lean layout can eliminate unwanted movements, transportation, and queue times, while a modular layout can allow for quick rearrangement and customization. A smart layout can leverage sensors, analytics, and artificial intelligence to monitor and improve the performance, quality, and life of the equipment and processes. A green layout can incorporate renewable sources, smart lighting and heating, and natural ventilation and cooling. A circular layout can facilitate the reuse, recycling, and recovery of items, as well as the prevention and reduction of muda. A human-centered layout can provide just enough space, lighting, and noises for the workers, as well as ergonomic tools and machinery. A collaborative layout can enable the interaction and co-working between humans and machines, as well as between different teams and functional areas. A compliant layout can present the alignment with the relevant norms, and policies, as well as the privacy of the data, workers and customers. A learning layout can support the feedback, evaluation, and experimentation of the processes and results. Small batch high mix/low volume manufacturing continues to grow in prominence, enabled by advances in machining, design and management. By classifying parts into families based on similarities, the Group technology approach provides manufacturers with an efficient way to manage the challenges of the Industry 4.0 era. Never to forget - Smart warehouses entail a series of self aware automation functionalities that work hand in hand to improve storage efficiency, productivity, and minimize human errors. For example, unloading by automated guided vehicles, automated vertical storage, order picking robots, and eco-friendly packaging are all managed by the latest software solutions.

**IX. 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 reimaging 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. Executives cite talent shortage as the biggest barrier in fulfilling their digital strategies. A comprehensive transformation program, envisioned by top management and involving the majority of the managerial workforces is required. Companies must tailor and customize their training to match both the goals of the firm and the needs of individuals right from CEOs to frontline operators. In addition to making use of technical content, successful reskilling programs are to be designed targeting the right mindsets.

2. Skilling and Reskilling Process Map.

A Corporate hub shall oversee the imparting of reskilling programs. Learning journey is shown below:

a. Companies must assess the nature, quality and quantum of futuristic skills.

b. Analyze the shortfalls in skills required to deliver on their strategic goals and ambitions of workforce.

c. Assess the underlying elements that can make or break a reskilling program.

d. Developing a robust strategy to capture these gap opportunities. ie, “rights killing” program.

e. Ensure the willingness of its people to embrace change.

f. Prioritize the skills that help the largest number of employees.

g. Envision the skill shifts of key roles.

h. Develop content.

i. Design delivery mechanisms for each of its priority modules.

j. Involving or gamification approach to train people in a new, digitally enabled working methods.

k. Give access to a library of add-on online apps in which they complement learning.

l. High performers receive both public recognition and financial reward.

m. Assess the impact of the program using right matrices.

n. Use agile techniques to test, adapt, and refine curricula and 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.

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| **Table 8: Workforce Mix** |
| 1.Soft workforceFlexible & 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.

**X. Inventory 4.0**

1. Lean Inventory.

How to efficiently and effectively manage inventory is a common challenge for all industries and companies. Inventory shall be smart which are carrying the data on their locations and dollar values. Based on real time information and data, inventory systems are able to automatically trigger the reorders with the right quantity at the right time. Inventory systems shall be able to foresee when and how much to order. Lead time variability shall be addressed with all the parties and entities sharing the information in real time. Inventory 4.0 provides the most convenience and great incentive for firms to start using the continuous review, than a traditional periodic system. The inventory policy is determined by solving an optimization problem that is composed of an objective function and constraints. The optimization problem is formulated based on the assumption on the system parameters. Through extensive deep data analytics, the the best inventory policy is expected to be achieved. Inventory matrices include quality, reliability, delivery, pricing, responsiveness and flexibility. Maintenance 4.0 machines are supposed to be able to automatically identify restock levels and place new orders by themselves. Smart Factory will be expected to have limited capacities and minimal inventory of the size of reorder level. Over the years, order sizes shall become smaller, but more frequent. Now, on to technological applications in inventory management. Automated guided vehicles (AGVs) and automated mobile robots (AMRs) are tools to help warehouse operators collect products from storage and pallets. Machine learning could be employed to spot out defective products or packaging so that customers only get quality items. A GPS location project shall be in place, where you track transit pallets, containers or delivery vehicles in real time to predict when items will reach their destinations. Cloud-based inventory management software allow for granular tracking of inventory down to the individual SKU or barcode, whether items are in a warehouse or in transit. Distributing inventory across multiple warehouses can reduce movement costs and speed up delivery times. Predictive picking software can direct businesses to initiate fulfillments before an order has even been thought of. A robust inventory management system allows companies to tap into personalization data to boost revenue. Firms with stock that’s not moving may also take measures to boost liquidity, including converting stale stock to cash by offering appealing offers or by bundling less popular items with best sellers. Automating SKU mapping, order fetching, real-time shipping rates and reorder notifications are part of Inventory 4.0. More advanced warehouse automation could use AI, cameras and sensors to assist a smart device navigate a warehouse and compile an order without human assistance. The key to success with 3PL is to connect all production sites, including the manufacturer and 3PL provider, such that they operate as a cohesive supply chain. We’ve also seen retailers shake hands with those 3PLs to store inventory and ship orders directly to end customers. Omni-channel inventory control requires coordination amongst store, distribution center and ecommerce operators to reconcile physical and online inventory and ensure price and offer. There are a number of instances of firms using block chain for inventory management and control.

2. Contemporary challenges of inventory management systems.

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| Coordination in restocking in multiple vendor setting with stochastic demandOptimizing dynamic inventory restocking and substitution for parts with long lead timesInventory Control in scenarios with random yieldTransshipment management of manufacturing facilitiesInventory Control for perishables with random offers.Rationing for systems with multiple demand classesOrdering Policies with unreliable vendors and counterfeit partsReplenishment by way of flexible contracts in spot marketInventory pooling techniques in case of information asymmetry |

**XI. Planning & Scheduling in Industry 4.0.**

1. De-congestion Management.

 In the yesteryears of manufacturing, scheduling was a simple process of determining what needed to be produced and assigning workers to complete the task. Gantt charts used to schedule and track the progress of manufacturing tasks. Critical path method breaks down a project into smaller tasks and determining the order in which tasks need to be completed. Assembly line balancing involves dividing a production line into workstations and assigning jobs to each station. Kanban is a system of cards to control the flow of materials and information between the production stages. MRP systems used data inputs viz customer orders, inventory status, and available capacity to create a practical production schedule. Dynamic scheduling systems rely on real-time data amassment. Data can be collected from multiple sources, such as sensors, ERP systems, and production machines. This allows manufacturers to respond to alterations in production environments as and when they happen. Sensors track the status of machinery and materials, measure performance, and identify constraints or issues that require attention. Data is analyzed in real-time to generate insights that could be used to optimize manufacturing. Capacity planning algorithms streamline production schedules based on available supply, demand, and other bottlenecks. Hence, manufacturers can minimize downtime, better the machine utilization, and enhance the overall production efficiency. So, orders are completed before due and to the asked for quality standards. In addition, algorithms can help manufacturers identify idle resources, reduce waste, and allocate resources better. APS software provides a centralized platform for administering shop floor data, scheduling, and other production-related jobs. APS can integrate with other softwares, such as ERP and MES. APS software enables manufacturers to make learned decisions about allocating resources and managing their workflows. As a result, manufacturers achieve real time visibility into their value chain. It has the capability to perform "what-if" scenarios, allowing makers to simulate different situations. The benefits include increased efficiency, shrinked costs, and customer delight. Recently, advanced scheduling techniques such as Finite Capacity Scheduling, Theory of Constraints or OPT, and Quick Response Manufacturing have come up. Machine learning algorithms can be deployed to optimize production plan. Machine learning models can create precise schedules that minimize downtime and maximize throughput. Manufacturers can cut waste, cut downtime, and add to efficiency by using sophisticated algorithms to optimize schedules based on bottlenecks. Finite capacity scheduling takes into account the limited capacity of resources such as machines, labor, and materials. TOC scheduling uses sophisticated OPT algorithm to identify these bottlenecks and optimize production. Critical chain scheduling optimizes scheduling by revolving around those critically constrained tasks. Hence, manufacturers can increase efficiency and reduce the risk of tardiness. Agile scheduling breaks processes into smaller manageable tasks, manufacturers can respond quickly to peaks or valleys in demand. Machine learning algorithms can zip through large amounts of data to predict outcomes, such as how long a specific production process will last. Information sharing tools like Microsoft Teams, Slack, and Asana are handy collaboration platforms. Real time information sharing tools like Power BI and Tableau are user friendly electronic dashboards. Video conferencing tools like Zoom have become popular for remote assistance in late years. Data analytics plays a crucial role in the resurgence of a dynamic scheduling system.

2. Role of Industry 4.0 tools in the revamp of PPC.

Algorithms & Data Models: Scaling to accommodate problems of scope and intricacy, and real-time replanning.

Artificial Intelligence:. Autonomous implementation of plan and schedule incorporating live response to changes.

Internet of Things: Makes available high quality, adequate volume data which provides timely information on the status of the operations, as well as the value chain.

Analytics: Processes plethora of data and provides the insights needed to generate real time plans and schedules.

Digital Twin: A digital twin that model scheduling before it happens on the factory.

Cloud: Budget friendly computing with the capacity to execute P&S 4.0 algorithms are available on demand.

Cyber physical Systems: Helps users to solve the delicacies of planning and scheduling problems.

Digital Supply Chain Management: A global, multi echelon approach towards the seamless supply chain.

Block chain: Secure communication between autonomous systems.

Mobility: Smart phones bring the power of P & S 4.0 to relevant users wherever they might be.

**XII. Smart Process Technologies.**

A central platform for data management is essential and developed according to use case. The enablers are Internet of things devices, enterprise apps like PLM, ERP, etc and MES. Building a data management foundation includes four components viz data acquisition, data management & storage, data processing, generation of insights and automatic execution of decisions.

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| **Table 9: Material Processing Technologies:**  | 4.CNC Machine tools |
| 1. Industrial Robots | 5. AGV - Automated Guided Vehicle  |
| 2. FMS - Flexible Manufacturing System  | 6. CIM - Computer Integrated Manufacturing  |
| 3. Process Control | 7. ASRS - Automated Storage and Retrieval  |

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| **Table 10: Information Processing Technologies:** | 3. Radio frequency identification  |
| 1. Internet  | 4. Extranet with Suppliers  |
| 2. DSS - Decision Support System  | 5. ES - Expert System |

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| **Table 11: Product Technologies:** | 3. CAE - Computer Aided Engineering  |
| 1. PLM - Product Lifecycle Management  | 4. CPC - Collaborative Product Commerce  |
| 2. GT - Group Technology  | 5. PDM - Product Data Management  |

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| **Table 12: Process Technologies:**  | 2. CAD/CAM - Computer aided Design & Manufacture  |
| 1. CAPP - Computer Aided Process Planning  | 3. STEP - Standard for Exchange of Product Model Data  |

**Conclusion of Chapter.**

The First Industrial Revolution was marked by a transition from manpower based production methods to machines powered by steam. Thanks to electricity, the Second Industrial Revolution transformed factories into modern manufacturing lines with high productivity and significant revenue growth. The Third Industrial Revolution saw computers like Programmable Logic Controller and communication technologies in the production process, leading to automated making. Industry 4.0, a brainchild from Germany, has become a internationally adopted term in the past 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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The authors have no conflict of interest relevant to this article.

References.

Abraham M, Annunziata M (2017) Augmented reality is already improving worker performance. Harvard Bus. Rev. (March 13), https://hbr.org/2017/03/augmented-reality-is-already-improving-worker-performance

Blanding M (2018) Printable future. Tuck School of Business News (October 15), http://www.tuck.dartmouth.edu/news/articles/printable-future

BMW Press release, "Fast, efficient, reliable: Artificial intelligence in BMW Group Production," July 2019.

BMW Press release, "Smart Data Analytics: BMW Group relies on intelligent use of production data for efficient processes and premium quality," August 2017.

Boeing, Innovation Quarterly, "A collaborative effort in machine perception research aids airplane inspection," November 2018.

Capgemini Research Institute, "Accelerating automotive's Al transformation," March 2019.

Capgemini Research Institute, "Smart factories @ scale," November 2019.

CBR, "How BMW optimised supply chain big data with Teradata," November 2016.

CIO, "Powering Digital Disruption at BMW," June 2016.

Cosmetics design-Europe, "Unilever invests in digital factories to harness supply chains", July 2019.

Customer Think, "How Al is reshaping the food processing business, January 2019.

DriveSpark, "Nissan's Idea: Let An Artificial Intelligence Design Our Cars", September 2016.

Food Drink & Franchise, "How Carlsberg is using Al to help develop new beers," January 2018.

Harvard Business School, "Bridgestone: Production System Innovation Through Machine Learning," November 2018.

Harvard Business School, "GM and Machine Learning Augmented Design, November 2018.

iFlexion, "Image Classification Everywhere in Automotive," September 2019.

Intel White Paper, "Artificial Intelligence reduces costs and accelerates time to market", June 2018.

Kellner T (2017) An epiphany of disruption: GE additive chief explains how 3d printing will upend manufacturing. GE reports. Accessed May 23, 2019, https://www.ge.com/reports/epiphany-disruption-ge-additive-chief-explains-3d-printing-will-upend-manufacturing/.

L'Oréal, "Industry 4.0 at L'Oréal," January 2018.

Micron Insights, "Case Study: Micron Uses Data and Artificial Intelligence to See, Hear and Feel," November 2018.

Microsoft, "Technology, luxury brands, and retail - a fashionable combination, January 2019.

Mitsubishi News Releases, "Mitsubishi Electric's Fast Stepwise-learning Al Shortens Motion Learning", February 2019.

Newswire, "Canon Showcases Solutions to Help Enterprises Embrace Lean Document Management Processes at the 2018 Association for Manufacturing Excellence," October 2018.

Shamma T (2017) Google glass didn’t disappear. You can find it on the factory floor. NPR (March 18), https://www.npr.org/sections/alltechconsidered/2017/03/18/514299682/google-glass-didnt-disappear-you-can-find-it-on-the-factory-floor.

Song J-S, van Houtum G-J, Van Mieghem JA (2019) Capacity and inventory management: Review, trends, and projections. Manufacturing Service Oper. Management, ePub ahead of print July 18, https://doi.org/10.1287/msom.2019.0798.

Thales Aerospace Magazine, "Assuring air safety and reliability-The Shift to Predictive Maintenance," May 2019.

Toolsgroup, "Ex Machina: Al and the Future of Supply Chain Planning," January 2016.