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Internet of things for smart factories in industry 4.0, a review

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ABSTRACT

The Internet of Things (IoT) is playing a significant role in the transformation of traditional factories into smart factories in Industry 4.0 by using network of interconnected devices, sensors, and software to monitor and optimize the production process. Predictive maintenance using the IoT in smart factories can also be used to prevent machine failures, reduce downtime, and extend the lifespan of equipment. To monitor and optimize energy usage during part manufacturing, manufacturers can obtain real-time insights into energy consumption patterns by deploying IoT sensors in smart factories. Also, IoT can provide a more comprehensive view of the factory environment to enhance workplace safety by identifying potential hazards and alerting workers to potential dangers. Suppliers can use IoT-enabled tracking devices to monitor shipments and provide real-time updates on delivery times and locations in order to analyze and optimize the supply chain in smart factories. Moreover, IoT is a powerful technology which can optimize inventory management in smart factories to reduce costs, improve efficiency, and provide real-time visibility into inventory levels and movements. To analyze and enhance the impact of internet of thing in smart factories of industry 4.0, a review is presented. Applications of internet of things in smart factories such as predictive maintenance, asset tracking, inventory management, quality control, production process monitoring, energy efficiency and supply chain optimization are reviewed. Thus, by analyzing the application of IoT in smart factories of Industry 4.0, new ideas and advanced methodologies can be provided to improve quality control and optimize part production processes.

1. Introduction

The fourth industrial revolution, known as Industry 4.0, includes smart factories as a key element in order to enhance efficiency in part production. Industry 4.0 is characterized by the incorporation of cutting-edge technologies into industrial processes to increase productivity, flexibility, and the Internet of Things (IoT), artificial intelligence (AI), and robotics [1]. A smart factory is a highly automated manufacturing facility in industry 4.0 that utilizes advanced technologies, such as artificial intelligence (AI), the Internet of Things (IoT), and robotics, to optimize its operations and improve its efficiency, productivity, and quality. Smart factories are facilities that use digital technologies to improve operational efficiency and productivity [2]. Smart factories are highly automated and connected factories which are relied on advanced technologies such as IoT, artificial intelligence, and robotics to optimize production processes and enhance operational efficiency [3]. In a smart factory of Industry 4.0, machines and equipment are interconnected and communicate with each other and with a central control system to enable real-time monitoring, analysis, and decision-making [4]. This allows manufacturers to optimize their processes, decrease environmental pollution, and increase flexibility to respond quickly to changing market demands. The application of IoT in smart factories is recently developed in order to drive the digital transformation of manufacturing, and enable companies to operate more efficiently, cost-effectively, and sustainably [5]. Smart factories are becoming increasingly popular, and IoT is a key technology in making these factories possible [6].

There are several constraints that need to be addressed for real implementation of Industry 4.0. Industry 4.0 implementation requires a large investment in advanced infrastructure and technology. For smaller businesses or those with fewer resources, this can be a significant obstacle. A highly qualified workforce with knowledge of digital technologies is needed for Industry 4.0 [7]. Companies should spend in

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employee training or new hire recruitment to fill these jobs with highly skilled personnel. There is a higher danger of cyber-attacks on the network's data as more devices and systems are connected to the internet. Implementing Industry 4.0 calls for strong security measures to guarantee the protection of sensitive data and intellectual property. Reliable and fast communication networks are essential for Industry 4.0 to be succeed. However, many places might not have access to the required infrastructure, which can make it difficult to execute Industry 4.0 in different companies [8]. To overcome these constraints, companies can consider the solutions in order to implement the industry 4.0 in process of part production. Companies can start by implementing Industry 4.0 technologies on a small scale to gain experience and build expertise before scaling up in big scale of companies [9]. Investing in workforce training and re-skilling programs can help companies develop the skills and expertise needed to operate and maintain Industry 4.0 technologies. Implementing robust data privacy and security protocols can help companies mitigate the risks associated with data collection and analysis [10].

In a smart factory, IoT technology is used to connect various machines, devices, and sensors to a central network. This helps to optimize the manufacturing process and reduce downtime [11]. A smart factory is the industry 4.0 version of the manufacturing process, which is more effective, adaptable, and sustainable. It enables companies to maintain their competitiveness in complex marketing conditions [12]. In a smart factory, interconnected devices, machines, and systems communicate with each other, making production processes more efficient, flexible, and automated. As a result, IoT devices can be used in smart factories to monitor and control various aspects of the production process [13]. For example, sensors can be used to track the temperature, humidity, and pressure in a production facility, while connected machines can provide real-time information about their status and performance. The obtained data can be analyzed by using artificial intelligence (AI) and machine learning algorithms in order to identify patterns and optimize production processes [14].

By optimizing processes and reducing downtime in smart factories, IoT devices can help manufacturers to save money in part production process. IoT sensors can also detect and alert workers in order to identify the potential safety hazards and prevent accidents and injuries for workers. However, managing and integrating a large number of IoT devices can be challenging, requiring specialized expertise and significant resources [15]. Also, IoT devices can be vulnerable to cyberattacks, which can compromise the integrity of the production process and put sensitive data at risk. Different IoT devices may use different communication protocols, which can make it difficult to integrate them into a cohesive system. IoT devices can generate vast amounts of data, which can be overwhelming to manage and analyze [16].

Sensor technology advancements in the era of the smart factory and industry 4.0 has been utilized to measure the conditions and parameters of manufacturing process such as temperature, humidity, and other environmental conditions in smart factories [17]. Also, IoT sensors in smart factories can be applied to monitor the entire manufacturing process, from raw materials to finished products [18]. This provides real-time data on production efficiency and quality, enabling manufacturers to make data-driven decisions to optimize their processes and improve their products [19]. IoT sensors can also detect and predict when machines will require maintenance, allowing for proactive maintenance to be performed before breakdowns occur [20]. Moreover, IoT sensors can be used to monitor the factory environment in order to detect potential safety hazards or security breaches. This can help to ensure that workers are safe and that valuable equipment and assets are protected [21]. The network of connected sensors allows machines to communicate with each other, share data, and coordinate their activities. This connectivity and coordination can greatly improve efficiency and productivity, and decrease waste and downtime in part production process [22]. IoT can be used to track inventory and manage the supply chain, enabling manufacturers to make informed decisions about production and distribution. This can save time and money while reducing downtime [23]. By leveraging the power of connected devices using energy saving methods, sensors, and software, manufacturers can improve efficiency, increase productivity, and enhance quality control using the IoT in industry 4.0 [24]. Also, factory managers can optimize production processes, reduce downtime, and improve quality control by leveraging the volume of obtained data during analysis process using the arterial intelligent and machine learning.

Predictive maintenance is another application of IoT in smart factories in order to reduce unplanned downtime by identifying potential equipment failures before they occur in machines and production equipment. So, factory managers can provide maintenance schedule and minimize downtime by analyzing data from sensors embedded in machinery and predict the potential equipment failures using IoT in smart factories [25]. IoT can also be used for inventory management, asset tracking, and energy management, among other applications. Smart factories use IoT devices to create a connected and automated environment that enables real-time monitoring, analysis, and control of manufacturing processes [26]. Blockchain integration with the next cybersecure industries regrading to the concept of industry 4.0 is examined in order to improve the applications of blockchain in smart manufacturing process [27]. In order to create the Cyber-Physical production networks, the Internet of things and arterial intelligence in sustainable smart manufacturing are studied [28]. In order to increase the effectiveness of smart factory technologies in the sophisticated part production process, the internet of things for manufacturing is studied [29]. Analysis of big data for green manufacturing is investigated in order to create the decision support algorithms for smart factories by using the internet of things [30]. Smart factories in the age of industry 4.0 is studied in order to enhance productivity of part production [31]. Industry 4.0's smart manufacturing system is studied in order to provide applications for the internet of things in advanced manufacturing and increase part production efficiency [32].

In order to present reliable cybersecurity for data visualization and tracking of the AGV status which improves decision-making and increases industrial efficiency, development of an IoT architecture based on a deep neural network has been investigated [33]. In order to present an advanced fault detection and correction method for induction motors, applications of IoT and deep learning technique in fault recognition and correction scheme is investigated [34]. In order to present online monitoring systems for CNC machining operations against cyber-attacks, applications of IoT platform and deep learning neural network algorithms are studied [35]. Convolutional neural network disease detection and classification are studied in order to increase productivity in the tomato farming process [36]. Exfiltration without privilege escalation for military and police units using a Bash Bunny is investigated in order to enhance the security of data in networks against cyberattacks [37]. In order to enhance security in position estimation of automated guided vehicles against different kinds of cyberattacks, application of robust kalman filter is investigated [38].

To evaluate and enhance CNC machining in virtual environments, Soori et al. proposed virtual machining approaches [39–42]. In order to enhance accuracy in 5-axis CNC milling operations, dimensional, geometrical, tool deflection and thermal errors are compensated by Soori and Arezoo [43]. To examine and improve efficiency in the process of component manufacture using welding processes, Soori et al. [44] proposed an overview of recent advancements in friction stir welding techniques. Soori and Asamel [45] investigated the utilization of virtual machining technologies to lessen residual stress and deflection error during turbine blade five-axis milling operations. In order to evaluate and lower the cutting temperature during milling operations of difficult-to-cut components, Soori and Asmael [46] developed applications of virtualized machining systems. To enhance surface qualities during five-axis milling operations of turbine blades, Soori et al. [47] presented an enhanced virtual machining technique. In order to minimize deflection error during five-axis milling procedures of impeller blades, Soori and Asmael [48] developed virtual milling procedures. In order to analyze and enhance the parameter optimization approach of machining operations, Soori and Asmael [49] offered a synopsis of current advances from published works. In order to increase energy usage effectiveness, data quality and availability throughout the supply chain, and precision and reliability during the component production process, Dastres et al. [50] conducted a research of RFID-based wireless manufacturing systems. In order to increase efficiency and added value in component production processes utilizing CNC machining operations, Soori et al. [51] examined machine learning and artificial intelligence in CNC machine tools. To measure and reduce residual stress during machining operations, Soori and Arezoo [52] provided a review in the subject. Soori and Arezoo [53] described optimal machining settings utilizing the Taguchi optimization technique to reduce surface integrity and residual stress during grinding operations of Inconel 718. Soori and Arezoo [54] investigated several tool wear prediction techniques to lengthen cutting tool life during machining processes. In order to increase efficiency in the component production process, Soori and Asmael [55] studied computer assisted process planning. In order to provide decision - making support systems for data warehouse operations, Dastres and Soori [56] discussed advancements in web-based decision support systems. In order to develop the implementation of artificial neural networks in performance enhancement of engineering products, Dastres and Soori [57] presented a review of recent research and uses of artificial neural networks in a variety of disciplines, including risk analysis systems, drone control, welding quality analysis, and computer quality analysis. Dastres and Soori [58] discussed using information and communication technology in environmental conservation to lessen the impact of technological progress on natural disasters. Dastres and Soori [59] proposed the secure socket layer in order to improve network and data online security. In order to create the methodology of decision support systems by assessing and recommending the gaps between presented methodologies, Dastres and Soori [60] analyze the advancements in web-based decision support systems. Dastres and Soori [61] provided an assessment of current developments in network threats in order to improve security measures in networks. Dastres and Soori [62] studied image processing and analysis systems to expand the possibilities of image processing systems in many applications. In order to analyze and enhance the effects of artificial intelligent, machine learning and deep learning in advanced robotics, recent achievements in published papers are reviewed by Soori et al. [63].

In order to analyze the effects of cutting parameter to the tool life and cutting temperature in milling operations, application of virtual machining system is developed by Soori and Arezoo [64]. Application of virtual machining systems in turning operations is investigated by Soori and Arezoo [65] in order to analyze the impacts of coolant on the cutting temperature, surface roughness and tool wear in turning operations of Ti6Al4V Alloy. In order to analyze and modify composite materials and structures, recent achievements from published papers are reviewed by Soori [66]. In the context of smart factories, IoT enables the creation of a digital twin of the physical factory, where real-time data from sensors, machines, and other devices can be collected and analyzed in order to optimize production processes, reduce downtime, and improve quality control [67]. IoT plays a crucial role in creating smart factories in Industry 4.0. It enables factories to be more efficient, productive, and safe by leveraging real-time data and AI algorithms [68].

Recent developments in internet of thing applications are studied and addressed in the study with the goal of evaluating and modifying the part manufacturing processes in smart factories of industry 4.0. Future research works from the gap between the achievement in published papers are also suggested in order to develop the applications of internet of things for smart factories in industry 4.0. So, the study can develop the smart factories of Industry 4.0 in order to optimize production processes, improve quality control, and enhance worker safety during part production process.

2. Predictive maintenance

One of the most important IoT applications in Industry 4.0's smart factories is predictive maintenance, which helps to minimize unscheduled downtime throughout the part-production process. Predictive maintenance can minimize equipment downtime and increase productivity during the component manufacturing process by utilizing data and analytics in order to estimate the repair time of machines and production equipment [69]. The process can be used in order to prevent downtime, reduce maintenance costs, and extend the operation time of machined and production equipment. IoT can facilitate predictive maintenance by continuously monitoring the health of machines and equipment, identifying potential failures before they occur, and providing maintenance schedule using the IoT in smart factories. IoT sensors are able to gather and communicate information about machinery and equipment, including information on temperature, vibration, and energy usage during chip formation process. Moreover, the process can be used in order to optimize maintenance schedules and minimize downtime in terms of maintenance enhancement of industry 4.0 [70]. IoT in 6G based smart factory of the industry 4.0 system from the supply management, process monitoring and control, sensors, AGV applications, inventory management and delivery management systems is shown in Fig. 1 [71].

Real-time performance and equipment health monitoring is possible using the IoT devices in terms of productivity enhancement of part manufacturing [72]. IoT sensors can monitor the condition of machines in real-time, predicting when they are likely to fail. These use data from sensors and other sources to predict when machines and equipment are likely to fail, allowing for proactive maintenance [73]. This process enables manufacturers to schedule maintenance before a breakdown occurs in order to reduce downtime and decrease part production costs [74]. Then, this data is analyzed to identify patterns and anomalies, which can be used in order to predict and schedule the maintenance when it is needed. Furthermore, IoT devices can be used to automate processes, such as material handling and product assembly [75]. This process can reduce the need for human intervention and improve efficiency by reducing the risk of human errors in product assembly and material handling [76]. Overall, IoT in smart factories is transforming the manufacturing industry, enabling predictive maintenance and real-time monitoring of the production process [77]. This leads to increased efficiency, reduced downtime, and improved product quality, ultimately driving growth and profitability. System architecture for the intelligent and predictive maintenance 4.0 is shown in Fig. 2 [78].

3. Asset tracking

IoT can be utilized in Industry 4.0 smart factories for asset monitoring, which is the utilization of sensors and other IoT devices to track the position and state of assets including machinery, tools, and raw materials in real-time throughout component production [79]. In a smart factories, asset tracking can be implemented by using the IoT devices in order to optimize production workflows, reduce downtime, and increase asset lifespan [80]. By providing precise, real-time information on the location and condition of assets, asset tracking can be applied in order to optimize the supply chain and manufacturing operations in smart factories [81]. By leveraging IoT sensors and devices, manufacturers can monitor and track the assets, such as machines, equipment, and tools, in real-time [82]. This process enables them to gain better visibility into their operations and improve productivity and profitability of part manufacturing. IoT-enabled asset tracking typically involves the use of wireless sensors that can be attached to assets and transmit data about their location, status, and condition to a central data repository [83]. IoT-enabled asset tracking systems use sensors and RFID tags to collect data on the location, status, and movement of assets. This data is transmitted to a central system in order to be analyzed and evaluated using artificial intelligent systems. Then, the analyzed data can be used in order to provide insights into the performance and utilization of the assets,

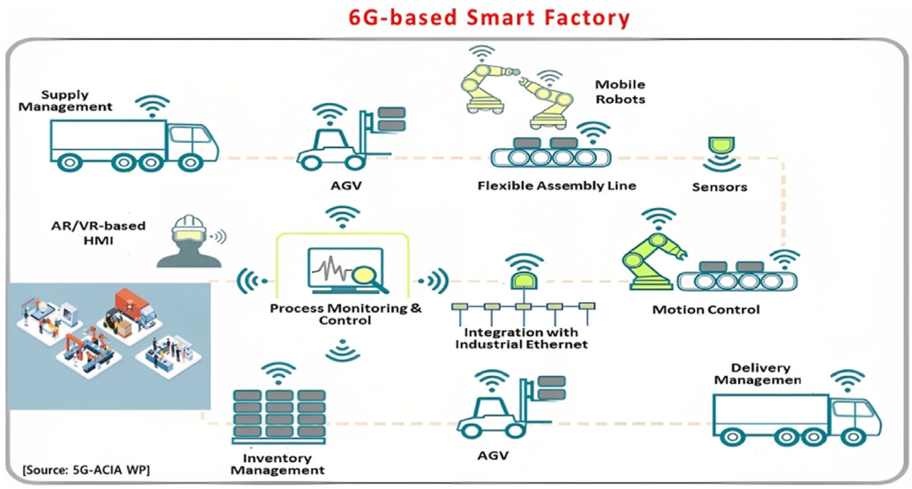

Fig. 1. IoT in 6G based smart factory of the industry 4.0 system [71].

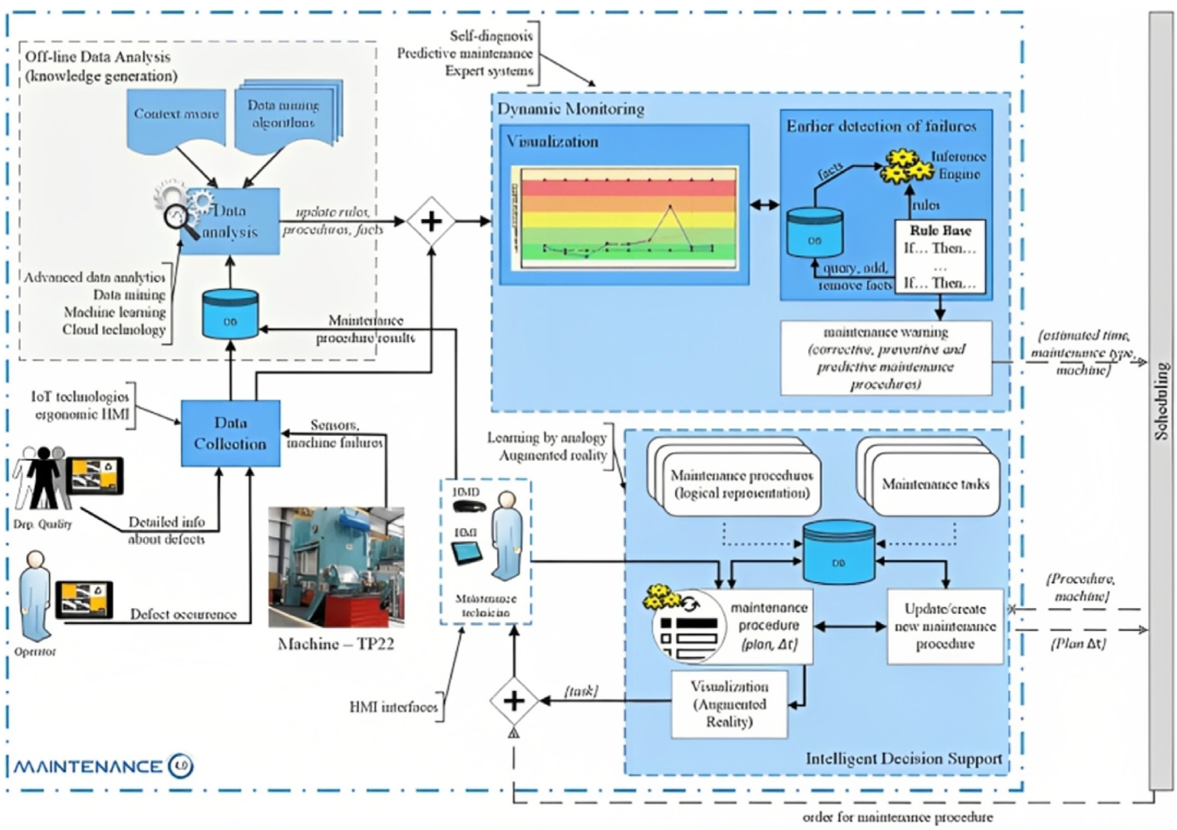

Fig. 2. System architecture for the intelligent and predictive maintenance 4.0 [78].

accurate data into the efficiency of production processes and identify potential maintenance or repair needs of machines [84,85].

By using real-time data, manufacturers can quickly identify bottlenecks and optimize production processes in order to minimize downtime and improve overall efficiency. For example, manufacturers can use IoT sensors to monitor the performance of their machines and equipment, and identify areas where they can be replaced during process of part production. They can also use asset tracking to ensure that tools and equipment are available when needed in order to reduce delays and improve productivity in part manufacturing [86]. Another key benefit of IoT-enabled asset tracking is providing accurate procedure for manufacturers in order to comply work with regulations and standards in process of part production. For example, in sensitive industries such as food and pharmaceuticals, it is essential to track the location and condition of products and materials to ensure their safety and quality [87]. IoT devices can be used to track the location and condition of equipment and materials in real-time. This enables managers to optimize equipment usage, reduce downtime, and improve maintenance schedules. Asset tracking in smart factories can also help manufacturers to manage inventory and enhance the environmental sustainability of part production [88]. By monitoring the movement of raw materials and produced parts, manufacturers can identify areas where the production pollution can be minimized and inventory management processes can be optimized. This procedure not only reduces costs of part production, but also improve the sustainability of manufacturing operations [89]. Overall, IoT-enabled asset tracking is a critical application of IoT in smart factories in terms of supply chain optimization process. It provides manufacturers with real-time data on the location and condition of assets in order to enable them to optimize production processes, decrease environmental impacts of part production, and improve overall efficiency of manufacturing process. Industry 4.0 tools and application fields in the asset tracking of electrical industry is shown in Fig. 3 [90].

4. Inventory management

IoT-enabled sensors can monitor inventory levels in real-time in order to provide manufacturers with accurate data on stock levels and enable them to optimize their production processes and decrease environmental pollution of part production in Industry 4.0 [91]. Smart factories use IoT devices to automate and optimize inventory management processes, reducing production costs, increasing efficiency, and improving accuracy of produced parts [92]. These are some ways which the IoT is being used in inventory management of smart factories.

1. Real-time tracking: Real-time inventory tracking is possible by using IoT sensors and RFID tags, which can provide precise and current data on stock levels, locations, and movements [93].
2. Automated replenishment: IoT devices can be used to automatically reorder inventory when stock levels fall below a certain threshold, reducing the need for manual intervention and ensuring that inventory levels are always optimal [94].
3. Demand forecasting: IoT sensors and data analytics can be used to analyze historical data and predict future demand, helping factories to optimize their inventory levels and reduce waste [95].

Real-time control and dynamic scheduling of the inventory management is shown in Fig. 4 [96].

Overall, IoT technology is helping smart factories in Industry 4.0 to optimize their inventory management processes and improve efficiency, accuracy, and cost-effectiveness.

5. Quality control

The IoT in smart factories can provide a powerful tool for quality control of produced parts in industry 4.0. IoT sensors can detect defects in real-time in order to provide accurate date for to quickly identify and rectify any issues and reduce the risk of defective products entering to the market. IoT sensors can monitor products as they move through the manufacturing process, identifying any defects or variations in quality [97]. The process can be implemented in order to ensure that every product meets the required standards of part production. By integrating sensors, devices, and machines into a network, IoT can collect and analyze data in real-time in order to provide insights into the production process and identify potential quality issues of produced parts regarding the standards of part production [98]. Here are some ways IoT can be used for quality control in smart factories.

1. Predictive maintenance: IoT sensors can be used to monitor the health of machines and equipment in real-time. This data can be analyzed to predict when maintenance is needed, which can help prevent downtime and improve the quality of products [99].
2. Real-time monitoring: IoT sensors can monitor various factors such as temperature, humidity, pressure, and vibration to detect any anomalies or deviations from the normal range. Any changes can be immediately flagged, and corrective action can be taken to prevent defects or quality issues [93].
3. Quality testing: IoT devices can be used to perform quality testing in real-time. For example, sensors can be used to check the weight or dimensions of products, or to detect any defects or abnormalities [100].
4. Traceability: IoT can be used to track products throughout the production process, providing a detailed history of each item. This information can be used to identify any quality issues and trace them back to their source [101].

Total quality management framework in Industry 4.0 is shown in Fig. 5 [102].

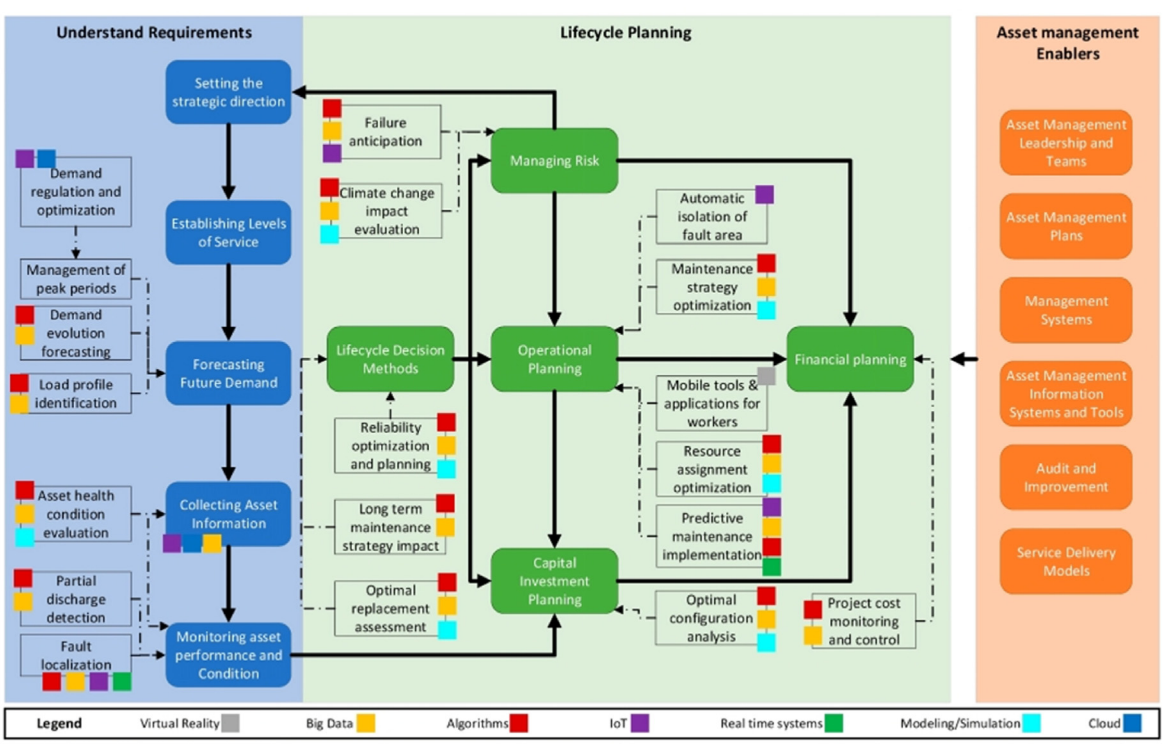

Fig. 3. Industry 4.0 tools and application fields in the asset tracking of electrical industry [90].

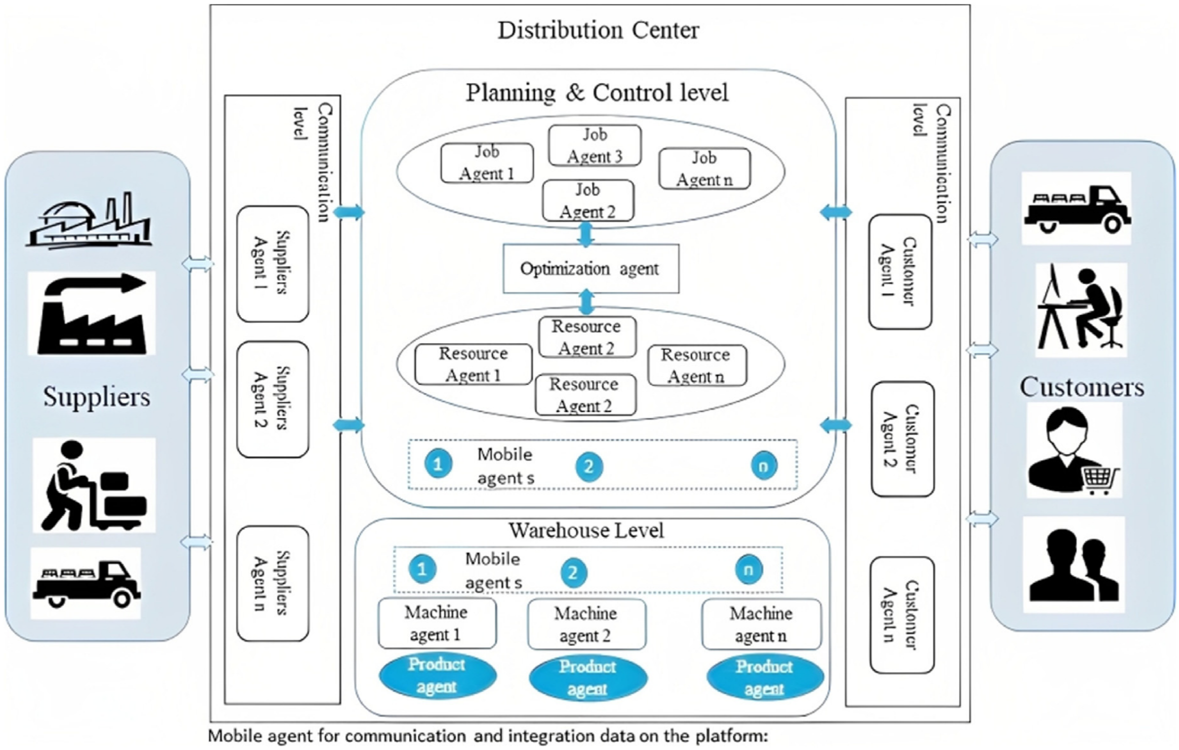

Fig. 4. Real-time control and dynamic scheduling of the inventory management [96].

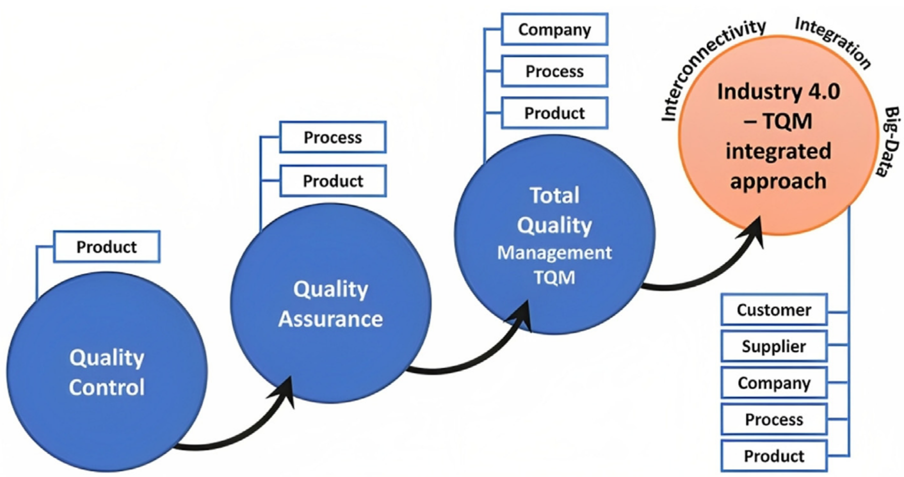

Fig. 5. Total quality management framework in Industry 4.0 [102].

Overall, the application of IoT in smart factories can improve the quality of products by providing real-time insights into the production process in order to enable factory managers to analyze and consider corrective action in quality assessment and modification of produced parts.

6. Production process monitoring

IoT-enabled production process monitoring is a critical component of smart factory operations in terms of quality enhancement of produced parts. By leveraging data from connected devices and sensors, factories can optimize production processes, reduce downtime, and improve product quality, in order to enhance efficiency and profitability of part manufacturing [103]. Production process monitoring in smart factories involves collecting data from IoT sensors and devices installed on production lines and equipment [104]. This data can be used to track key performance indicators (KPIs) such as production output, machine utilization, and product quality. By monitoring these KPIs in real-time, factory managers can quickly identify bottlenecks, inefficiencies, and other issues that may be affecting the production process [105]. IoT-enabled devices and sensors can be used to monitor and control various aspects of the manufacturing process, including production lines, machinery, equipment, and inventory. For example, sensors can be used to track the temperature, humidity, and other environmental conditions in the factory, ensuring that the products are produced in optimal conditions [106]. They can also be used to monitor the performance of machines and equipment in terms of online condition monitoring of part production process. By connecting devices, sensors, and machines to a network, data can be collected in real-time, allowing for a more efficient and streamlined production process [107]. Another example of production process monitoring is optimization of supply chain during part production process. IoT sensors can be used to track inventory levels and monitor the supply chain in terms of part production optimization process. Also, the IoT sensors can be used to track the movement of raw materials and finished products throughout the factory and supply chain, providing real-time visibility into inventory levels, shipping schedules, and other critical information [19]. This procedure can be utilized in order to optimize supply chain and reduce inventory costs in terms of productivity enhancement of part manufacturing [108]. Overall, the IoT can help manufacturers monitor and optimize the production process in real-time, allowing for greater efficiency, improved quality control, and cost savings [109]. Fig. 6 depicts an online process monitoring program used in Industry 4.0 [110].

7. Energy efficiency

IoT devices can monitor energy usage throughout the factory and identify areas where energy efficiency can be improved. This can help reduce costs and lower the factory's carbon footprint. IoT devices can monitor energy consumption in real-time and identify areas where energy usage in part manufacturing can be optimized. The process can be implemented to reduce energy costs and improve sustainability in part production [111]. By using IoT technology, smart factories can monitor and optimize energy consumption in real-time, resulting in significant energy savings and cost reductions [112]. Here are a few ways in which IoT can help improve energy efficiency in smart factories.

1. Energy Monitoring: IoT sensors can be used to monitor energy usage in real-time across different areas of the factory, from production lines to lighting and heating systems. This data can then be analyzed to identify areas of inefficiency and opportunities for optimization [113].
2. Automated Control Systems: IoT devices can be used to automate energy usage across different systems in the factory. For example, lighting and heating systems can be automatically adjusted based on occupancy levels or ambient temperature [114].
3. Renewable Energy Integration: IoT technology can help smart factories integrate renewable energy sources such as solar or wind power in order to provide sustainable production process. Also, The process can help reduce reliance on fossil fuels and lower energy costs in terms of energy consumption management of manufacturing process [115].
4. Smart lighting: IoT devices can be used to control lighting in factories. This can include automatically turning off lights in unoccupied areas, dimming lights based on the amount of natural light in a room, or adjusting lighting to match the tasks being performed in a particular area [116].
5. Energy-efficient HVAC: IoT devices can be used to monitor and optimize heating, ventilation, and air conditioning (HVAC) systems. This can include adjusting the temperature based on occupancy or outside weather conditions, or using sensors to detect when a space is unoccupied and reducing HVAC usage accordingly [117].
6. Energy storage: IoT devices can be used to manage energy storage systems. This can include charging batteries during off-peak hours when energy is cheaper and using stored energy during peak hours when energy is more expensive [118].

Energy-saving techniques in wireless sensor networks for smart factories in the industry 4.0 is shown in Fig. 7 [114].

Overall, IoT technology has the potential to transform energy efficiency in smart factories, resulting in significant energy savings, cost reductions, and environmental benefits. By leveraging IoT technology in smart factories, manufacturers can optimize their energy usage, reduce costs, and minimize their environmental impact [119].

8. Safety monitoring

IoT devices can be used to monitor employee safety, ensuring that workers are following safety protocols and that any hazards are identified

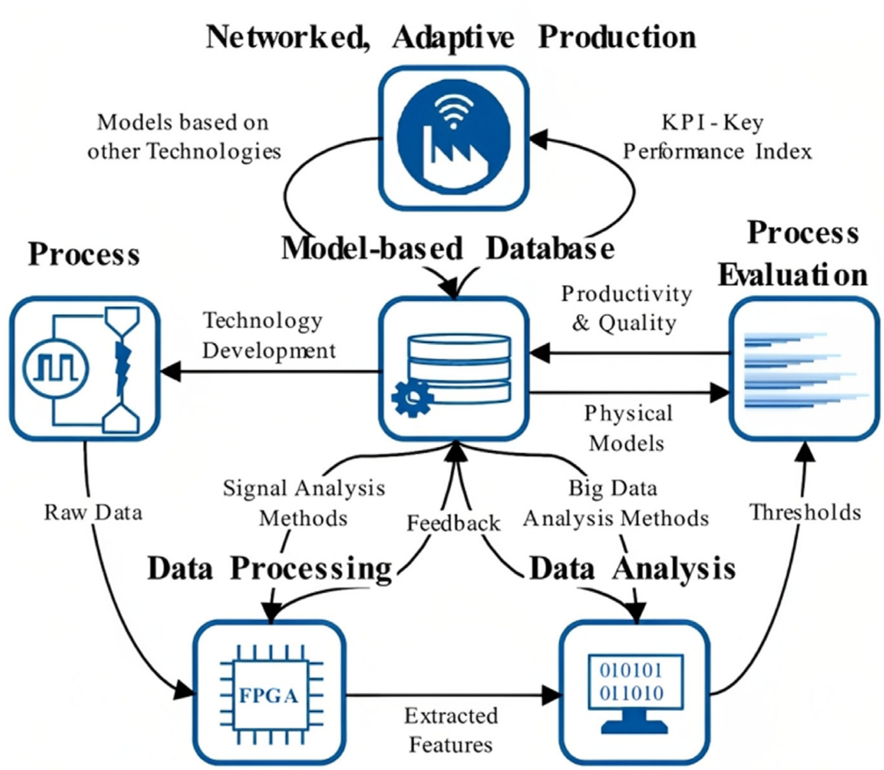

Fig. 6. Online process monitoring system within the scope of Industry 4.0 [110].

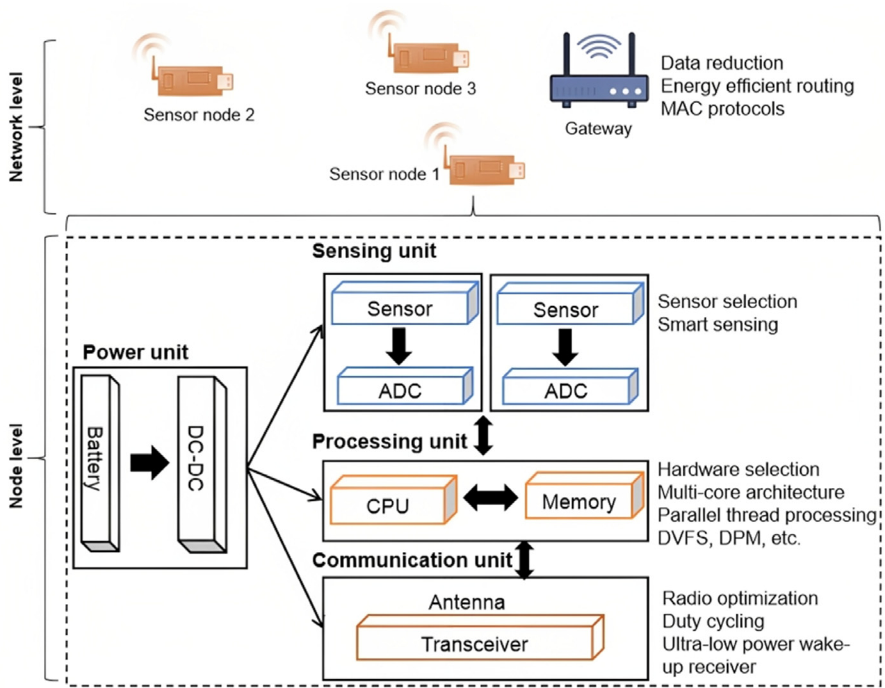

Fig. 7. Energy-saving techniques in wireless sensor networks for smart factories in the industry 4.0 [114].

and addressed quickly. One example of IoT-enabled production process monitoring is predictive maintenance for production machines and equipment [120]. It is possible to identify indicators of wear and tear or other problems that might portend an oncoming breakdown in the component production process by gathering data from sensors on machines and equipment [121]. The implementation of safety monitoring procedure can help factory managers to provide accurate maintenance schedule, in order to reduce downtime and prevent costly production delays [122]. Here are a few ways IoT can enhance safety monitoring in smart factories.

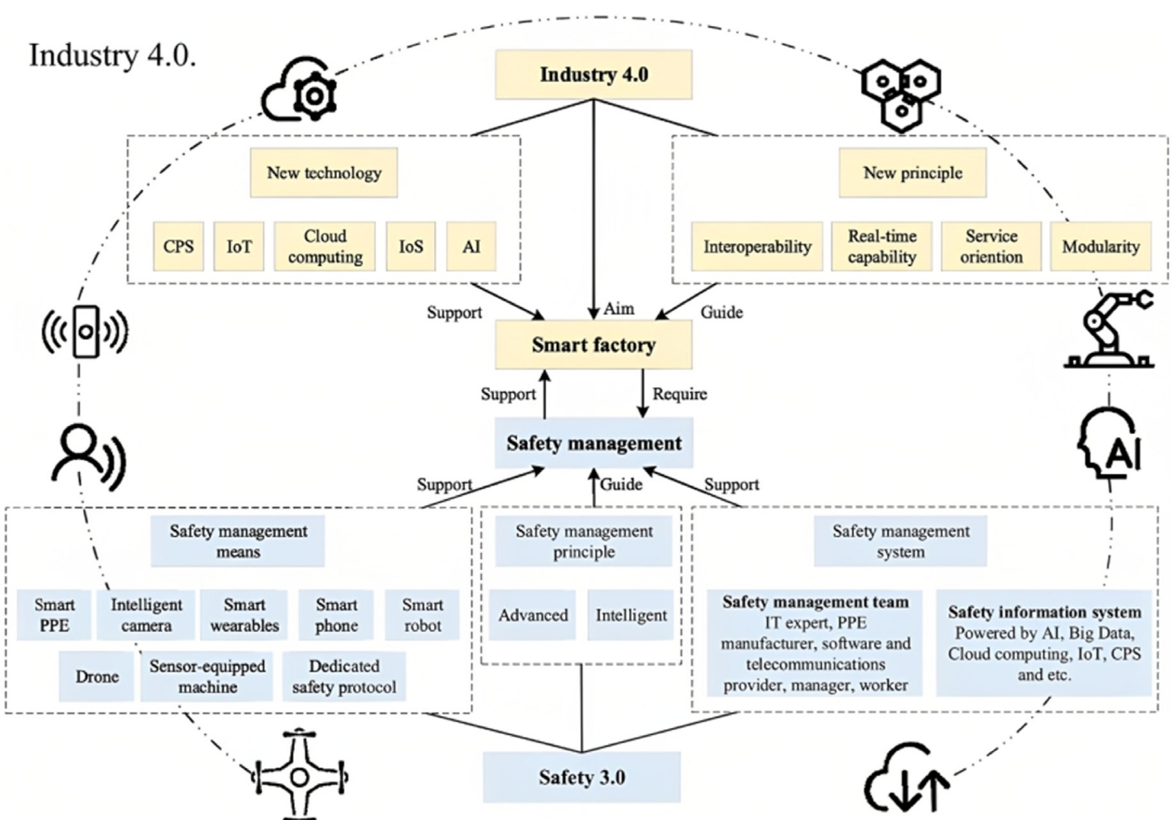

Fig. 8. The integration of Safety and Industry 4.0 [127].

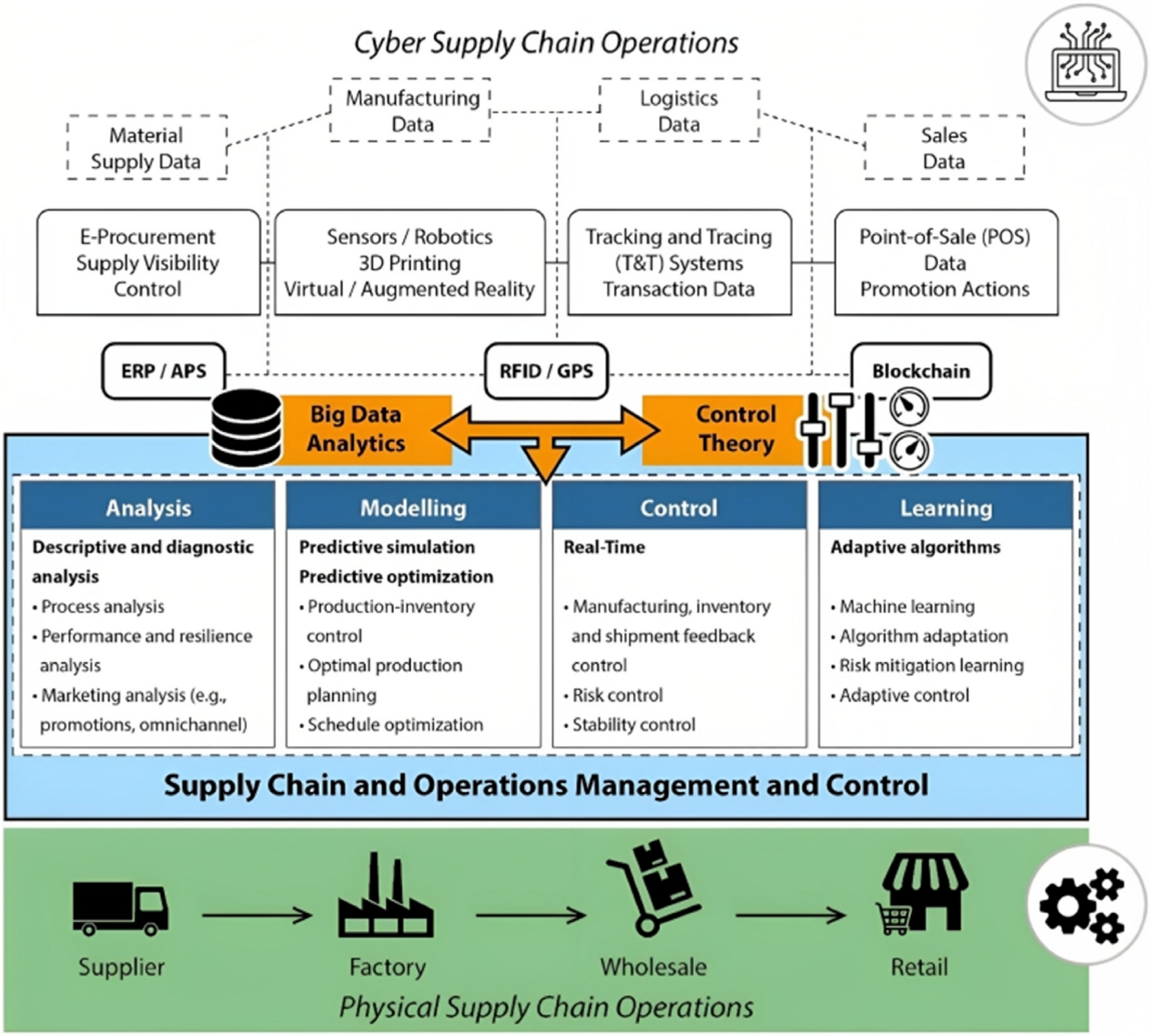

Fig. 9. Digital supply chain and operations control in industry 4.0 [136].

1. Real-time monitoring: IoT sensors can continuously monitor factory conditions such as temperature, humidity, and gas levels. This data can be analyzed in real-time to detect potential hazards and alert workers before an incident occurs [123].
2. Predictive maintenance: IoT can help predict when equipment is likely to fail, allowing for proactive maintenance to prevent accidents caused by faulty machinery.
3. Automated alerts: IoT can automatically generate alerts when unsafe conditions are detected, such as high levels of toxic gas or abnormal temperature spikes [124].
4. Wearable devices: IoT-enabled wearable devices can monitor workers' vitals and alert supervisors when an employee is experiencing stress or fatigue, reducing the risk of accidents caused by human error [125].
5. Safety analytics: IoT-generated data can be analyzed to identify patterns and trends that can help factory managers improve safety procedures and prevent accidents in the future [126].

The integration of Safety and Industry 4.0 is shown in Fig. 8 [127].

Overall, IoT technology can enhance safety monitoring in smart factories by providing real-time data and predictive analytics, enabling proactive maintenance and alerting workers to potential hazards [128].

9. Supply chain optimization

The Internet of Things (IoT) has the potential to revolutionize supply chain management and optimization in smart factories in order to enhance productivity in part manufacturing. IoT can be used in smart by applying the (Radio Frequency Identification) RFID tags in order to obtain accurate data from the parts and products [129]. These tags can be attached to products or materials, and their movement can be tracked in real-time [130]. So, the process allows supply chain managers to monitor the location and status of their inventory, enabling them to optimize inventory levels and ensure timely delivery of products. Another example is the use of predictive maintenance [131]. IoT can also be used to optimize the transportation of goods within the supply chain. It can be used to track shipments in real-time, providing manufacturers with accurate information about the location and status of their products. For example, by using GPS tracking and real-time data analytics, logistics managers can optimize delivery routes, reduce transportation costs, and improve delivery times [132]. The implantation of process can help manufacturers to optimize supply chain and reduce delays in order to improve productivity and customer satisfaction in process of part production. IoT devices can be used to monitor the movement of materials and products throughout the supply chain. This enables managers to optimize logistics, reduce inventory costs, and improve delivery times [133]. IoT-enabled devices can provide real-time data on the location and status of raw materials and produced parts in order to enable manufacturers to optimize their supply chain operations and improve overall production efficiency [134]. Overall, IoT offers many benefits for supply chain optimization in smart factories, including increased efficiency, reduced costs, improved productivity, and better visibility into the supply chain [135]. As the technology continues to develop the smart factories, it is expected to see even more innovative ways in which IoT can be used to improve supply chain management. Digital supply chain and operations control in industry 4.0 is shown in Fig. 9 [136].

10. Conclusion and future research work directions

Smart factories are factories that use connected devices and real-time data to optimize production processes, improve efficiency, and minimize environmental pollution of part production. The IoT is a critical component in the development of smart factories in terms of productivity enhancement of part production. IoT has the potential to revolutionize the manufacturing industry by improving efficiency, reducing costs, and increasing productivity. IoT devices can automatically reorder items when inventory levels fall below a certain threshold, reducing the need for manual intervention and ensuring that inventory is always at optimal levels. By connecting machines, devices, and sensors, smart factories can improve efficiency, productivity, and safety, and reduce waste and downtime in part manufacturing process. IoT can provide end-to-end visibility of the supply chain, allowing factory managers to track inventory from the supplier to the factory and then to the end customer. The process can be used in order to optimize the supply chain, reduce lead times. Smart factories are just the beginning of what is possible with this technology. IoT sensors can be used to monitor environmental factors such as temperature, humidity, and air quality, ensuring that the factory environment is safe and comfortable for workers. Moreover, IoT sensors can be attached to inventory items and placed throughout the factory in order to track their location and movements. As a result, managers know exactly where the inventory is located at any given moment, reducing the risk of lost or misplaced items.

IoT sensors can track inventory levels in real-time, helping manufacturers optimize their inventory levels and avoid stockouts. The process can reduce production delays and ensures that manufacturers always have the materials they need to meet customer demands. As a consequence, the inventory levels can be optimized in order to reduce the stockouts and overstocking conditions in part production process. IoT sensors can collect data on product usage and demand, enabling factory managers to predict when certain items will need to be restocked. IoT sensors can monitor the conditions of the inventory, such as temperature and humidity, to ensure that they are stored in optimal conditions. IoT devices can monitor product quality in real-time, detect defects, and trigger alerts if quality standards are not met during part production. As a result, factory managers can quickly take corrective action and prevent defective products from leaving the factory. IoT-enabled machines can also be used to automate production processes, reducing the need for manual intervention and increasing production efficiency. The IoT is transforming inventory management in smart factories by providing real-time data, automating processes, and improving visibility. By utilizing these technologies, factories can increase part manufacturing productivity, reduce waste materials, and improve inventory management procedures in process of part production. Overall, the IoT is poised to revolutionize the way smart factories operate. With IoT-enabled devices, factories can collect and analyze data in real-time, optimize operations, and improve efficiency. However, there are still many areas of IoT in smart factories that require further research. Here are some potential future research work directions.

1. Security and privacy: As more devices are connected to the Internet, security and privacy become critical concerns. Research can explore new ways of securing IoT devices and networks to prevent cyber-attacks, data breaches, and other threats. Future research could focus on developing secure and privacy-preserving IoT architectures for smart factories [69].
2. Edge computing: Edge computing involves processing data closer to the source rather than sending it to the cloud. In smart factories, this can help reduce latency, improve response times, and enable real-time decision-making. Future research can focus on developing more efficient and effective edge computing algorithms and architectures.
3. Machine learning and artificial intelligence: Machine learning and artificial intelligence (AI) can help smart factories optimize production processes and improve efficiency. Future research could explore the use of machine learning and AI in smart factories, and how these technologies can be used to drive innovation and improve outcomes.
4. Interoperability: The lack of interoperability between IoT devices from different vendors is a significant challenge. Research can explore ways to improve interoperability through open standards, protocols, and APIs, which can help manufacturers integrate different devices and systems.
5. Energy efficiency: IoT devices require a constant supply of power, which can be a challenge in factories where power is limited or expensive. Future research can focus on developing more energy-efficient IoT devices, networks, and architectures to help reduce energy consumption and costs.
6. Integration with Supply Chain: IoT-enabled smart factories can be integrated with supply chain systems to improve logistics, minimize the environmental impacts of part production, and enhance overall efficiency of part manufacturing. Future research could focus on developing robust and scalable architectures for integrating IoT-enabled smart factories with supply chain systems.
7. Integration with other systems: Smart factories will need to be integrated with a wide range of other systems, including supply chain management systems, logistics systems, and customer relationship management systems. Future research could explore the best ways to integrate these systems with smart factories, and how to ensure that data is transmitted seamlessly between them.
8. Decision making: Smart factories utilize IoT devices and sensors to gather data about various aspects of the production process, which can then be used to make accurate decisions in real-time. Decision making in IoT-enabled smart factories involves collecting and analyzing data, implementing decision-making algorithms, monitoring operations in real-time, and leveraging human expertise to make informed decisions. By using IoT technologies, factories can optimize operations and improve productivity, leading to better business outcomes.
9. Cloud manufacturing: Cloud manufacturing refers to the use of cloud computing technologies to support manufacturing processes. The combination cloud manufacturing and the IoT in industry 4.0 can develop the traditional manufacturing processes into highly automated, data-driven operations that are more efficient, flexible, and responsive to customer needs.
10. Machine Learning and Artificial Intelligence: The integration of machine learning and artificial intelligence (AI) with IoT devices can enable smart factories to make more intelligent and autonomous decisions. Future research can focus on developing AI algorithms that can learn from data generated by IoT devices and make decisions that optimize factory processes.
11. Autonomous systems: IoT devices can be used to create autonomous systems that can perform tasks without human intervention. Research can focus on developing new algorithms and techniques that can improve the performance of these systems, making them more efficient and effective.
12. Human-machine interaction: Smart factories are becoming increasingly automated, but humans still play a crucial role in monitoring and managing the manufacturing process. Research can explore ways to improve the interaction between humans and

machines, such as through augmented reality, natural language processing, and other technologies. IoT-enabled smart factories will require workers to interact with connected machines and devices. Future research could focus on developing intuitive interfaces and augmented reality systems to enhance human-machine interaction in smart factories.

Overall, IoT has enormous potential to transform smart factories and the manufacturing industry in order to enhance accuracy and productivity in process of part production. Future research can help address the challenges and opportunities of IoT in smart factories, leading to more efficient, productive, and sustainable manufacturing processes. Future research will play a critical role in driving this innovation and ensuring that the IoT is used in a way that benefits everyone.

Declaration of competing interest

I confirm that there is no conflict of interest regarding the submitted manuscript with title of **'Internet of Things for Smart Factories in Industry 4.0, A Review'** to the Internet of Things and Cyber-Physical Systems.

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