SN Computer Science (2020) 1:232
https://doi.org/10.1007/s42979-020-00248-2

REVIEW ARTICLE

Internet of Things (IoT) in Pharmaceutical Manufacturing, Warehousing, and Supply Chain Management

Apoorva Sharma[1] · **Jaswinder Kaur**[2] · **Inderbir Singh**[1]

Received: 28 December 2019 / Accepted: 6 July 2020 / Published online: 16 July 2020

Abstract

Internet of Things (IoT) is a buzzword in the area of information technology. The Internet of Things is an interconnected computer system with unique identifiers (UIDs) that are capable of transmitting information over a network. This review article highlights the potential applications of IoT in pharmaceutical manufacturing, warehousing, and supply chain management to enhance product quality, increase productivity, and reduction in errors during different stages of a pharmaceutical product. During the manufacturing of the pharmaceutical product, IoT may be useful in supervising and optimizing different unit operations for real-time monitoring and control to enhance production efficiency. In warehousing and supply chain management of pharmaceutical products, IoT is applicable in monitoring the real-time storage conditions of the drug product and improving visibility to enhance operational effectiveness.

Keywords Internet of Things · RFID tags · Sensors · Manufacturing · Warehousing · Supply chain management

Abbreviations

IOT	Internet of Things
RFID	Radio Frequency Identification
UID	Unique identifier
WSN	Wireless sensor networks
MEMS	Microelectromechanical System
OEE	Overall equipment effectiveness
GMP	Good Manufacturing Practice
ADC	Analog-to-digital converter
AGV	Automated Guided Vehicle

Introduction

After the emergence of information technology enabled services, there is a sea change in the day-to-day routine of human beings as well as in the functioning of industries and organizations. This is turning out to be a prominent model through most of the vertical and horizontal commerce, including the daily routine of a common man, as it has great significance. The evolution of the Internet of Things (IoT) is mainly due to the requirements by the large-scale industries, which benefits highly from its ability to predict and foresight and to track all objects through the supply chains in which they are placed. IoT-based applications are useful in industries to track the coded objects, which results in a reduced error, theft prevention, speed up processes, and companies becoming more efficient, and introduce flexible and complex organizational systems. IoT is an advanced technological breakthrough representing the advancements in computing and communications, nanotechnology, and wireless sensors [1].

The Internet of Things is a revolutionary paragon in the IT world. *Internet of Things*, also termed IoT, is composed of two words, "Internet" and "Things". The term Internet is a worldwide network of interlinked computer systems that employ the standard Internet protocol suite (Transmission Control Protocol/Internet Protocol), which connects millions of people around the world. It is a massive network

✉ Inderbir Singh
inderbir.singh@chitkara.edu.in

Apoorva Sharma
apoorvas5346@gmail.com

Jaswinder Kaur
jaswinder.kaur@thapar.edu

[1] Chitkara College of Pharmacy, Chitkara University, Punjab, India

[2] Electronics and Communication Engineering Department, Thapar Institute of Engineering and Technology, Patiala, Punjab 147004, India

incorporating millions of public, private, commercial, educational, and government networks that are connected locally and globally via a wide variety of wireless, computerized, and optical networking technologies. Any person with a cardiac implant, a farm animal with a biochip transponder, or any automobile having inbuilt sensors could be referred to as 'Thing' in the Internet of Things. In IoT, 'Things' could be designated as the RFID (Radio Frequency Identification) tags, sensors, actuators, mobile phones, and such things via an eccentric addressing scheme are capable of interacting with each other and comply with the surroundings to accomplish the collective goals [2]. IoT was developed from the conjunction of the microelectromechanical systems (MEMS), wireless technologies microservices, and the Internet.

Kevin Ashton, the specialist in the field of digital technology, was the first one to use the term Internet of Things. The concept that is common in all the definitions of the Internet of Things is that the first Internet version comprises of information generated by people, while the next version comprises of information that is associated with the objects. As for now, there is no such distinctive definition for the Internet of things that is available for the users.

The Internet of Things could be best described as:

"An open and detailed networks of smart objects that can self- organize, share information, data and resources, react and respond in reaction to situations and changes in the environment" [1].

The Internet of Things had a major influence on multiple businesses around the globe. However, in embracing the technical changes, the pharmaceutical sector has become very pragmatic and, therefore, the impact of IoT has not yet been felt strongly across the pharmaceutical and medical device industry. Nonetheless, IoT has extensive ability to help the pharmaceutical firms to increase their production efficiency, minimize costs, and also modify their method of delivering medicines to the consumers. IoT eliminates the gap between the doctor, the pharmaceutical supplier, and the consumer by tracking the patient's adherence with the prescribed medication in the cloud. With the help of IoT, the pharmaceutical industry can save more lives, and discover treatments and effective care with the help of sensors and smart devices. IoT on the one end provides the industry with increased efficiency and resilience and profitability; on the other, it offers immense breakthrough possibilities that can contribute to new era of transformation in Pharma world.

Some Key Challenges of IoT

The typical IoT models are complicated because of their enormous effects on human life (e.g., safety, mobility, environmental sustainability, security, energy efficiency, health, etc.). Therefore, the problems and challenges related to IoT must be taken into account in the light of different outlooks such as community and environmental impacts, enabling technologies, commercial models, services, and applications [3].

Some of the challenges to IoT are discussed below [4]:

1. Data Management Challenge: IoT devices employed for diverse application generate huge amount of data which is required to be stored, managed, and analyzed adequately.
2. Data Mining Challenge: Data generated through IoT devices could be traditional discrete data or streaming data generated from digital sensors. As more data are available for processing and analysis, the use of data mining tools becomes necessary. Computer and mathematical models could be applied for screening/understanding the data requirements.
3. Privacy Challenge: IoT devices can provide a vast amount of data on IoT users' location which can spark significant privacy concerns. Protecting privacy is often counterproductive to service providers.
4. Security Challenge: Although the use of IoT-based technologies has improved industrial productivity and overall quality life of people. However, security concerns of attack by hackers and other cyber criminals should be catered seriously with increasing use of IoT.
5. Chaos Challenge: IoT-based technologies need to address the issues related to privacy, insufficient, complex communications, and poorly tested devices. If not designed and monitored carefully, IoT technologies can turn our lives into chaos.

Technologies

Internet of Things may be seen as a large complex environment comprising of multiple linked real-world entities that rely on networking, data processing, sensory, and communication technologies [5]. RFID is the chief technology for IoT that functions by permitting the microchips to transmit the data to the receiver via wireless technology. Using RFID, the objects embedded with the RFID tags can be tracked, monitored, and analyzed [6]. Another necessary IoT technology is Wireless Sensor Networks (WSNs), which primarily functions on smart sensors for monitoring and sensing. Since the 1980s, RFID has been used in the production, distribution, and retail of the pharmaceutical products [6, 7], and WSN is being applied to healthcare and industrial supervision. The development of IoT is driven by the advancement in both the technologies. There are several other technologies and devices, such as ZigBee, barcodes, Wimax, near-field communication, cloud computing, location- based service,

etc. that are being employed for creating a secure IoT system [8] (Fig. 1).

Lee and Lee (2015) discussed essential IoT technologies as under [9]:

1. Radio-frequency identification (RFID): The RFID helps in identifying, tracking, and transferring data. RFID tags have five main classes [10]. The class 1 tags contain passive tags with a read/write memory. Class 2 tags have security regarding formalities. Class 3 comprises of the semi-passive tags and are driven by a battery and may have sensors. The class 4 tags active tags are also battery-driven and they can interact with similar alike tags. Finally, class 5 tags helps in activating the other tags and is linked directly to the back-end networks.
2. Wireless sensor networks (WSN): It is a sensor network for tracking and controlling the status of various devices like their temperature, noise, location, and movement. Temperature, flow level, infrared, air pollution, moisture proximity and displacement, pressure, and speed are being monitored the use of sensors [11]. WSN can collaborate and interact with RFID tags [12].
3. Middleware: Middleware is a service-intended software layer. This layer permits the software developers the probability of developing interaction with heterogeneous devices like RFID tags, sensors, and actuators.
4. Cloud computing: Cloud computing is an Internet-built computer program. It contains various computing resources (computers, software, storage, network, etc.) that can be distributed and read on request. Because of the large volume of information being generated by IoT devices, cloud computing is essential [12]. There are many IoT cloud platforms available in the market which performs in a fashion similar to the middleware software. Their primary objective is to link IoT devices and their applications. Cloud-computing services appear to be an effective solution for data center ownership and management. However, the industries might require local and on-site storing, computing, and conveying abilities for some latency-sensitive applications [13]. The main idea of fog computing is to combine local and cloud-computing services. It contains 'a highly virtualized' program which allows storage, evaluating and networking facilities between end systems and traditional cloud-computing information centers [13]. The utilization of IoT requisite geographical distribution, mobility succour, location information, and low latency could be achieved by fog computing proficiencies [14].
5. IoT applications: They facilitate in system-to-system and human-to-system connections. IoT applications comprises of the interface linking the user and the devices. The data are proposed in an intuitive way must be proficient enough to present data in an intuitive way, identify problems, and recommend solutions.

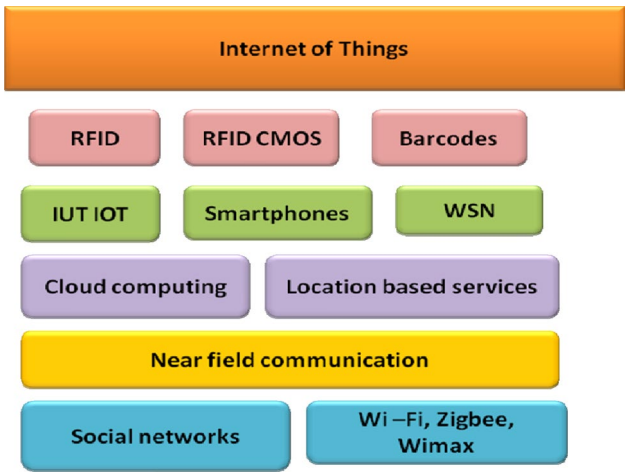

Fig. 1 Technologies empowering IoT

Application of IoT in Pharmaceutical Value Chain

Although IoT is still in its nascent stages of adoption in the pharmaceutical industry, the use of smart devices and machine-to-machine communication technologies are widely being used for digitization of processes and data. IoT is creating innovation by disrupting the old conventional models in the heavily regulated pharmaceutical industry from making to the distribution of the drugs. Pharmaceutical manufacturers are now much more receptive to experimenting with IoT technologies for improving quality, increasing productivity, reducing production errors, and increasing the expectations of the stakeholders concerning drug efficacy. The use of IoT in pharmaceutical manufacturing, supply chain, clinical development, and patient engagements not only helps in reducing time to market for drugs but also detects errors across the value chain through real-time data feed to improve regulatory compliance. The use of IoT in manufacturing and supply chain management is a common area of investment for various industries. Some of the standard applications of IoT that are particularly well suited for many pharmaceutical industries are the connected equipment, materials, men, smart packaging, cold chain monitoring, and sample lifecycle management. Most of the pharmaceuticals manufacturing operations are generally performed in batches, and the equipment is mostly self-contained. The executives are not available to make informed decisions for improving the overall equipment effectiveness (OEE) in areas like scheduling and maintenance of the batches because of insufficient information on the condition of the equipment, even though there is well established industrial automation and control

technologies. IoT technologies facilitate the companies to connect and expand their visibility into the activities of the shop floor to enhance production significantly and confirm with the GMP compliance (Fig. 2).

IoT in Pharmaceutical Manufacturing

Batch production in the pharmaceutical industry has been underway for the past few years, but automated processing systems can be applied not just to regulate equipments and materials, but also to improve drug production efficiencies and other relevant activities. IoT-enabled devices can relay operational data conveniently to other devices or manufacturing engineers. And this information helps to manage the industry in such a way which helps to enhance the productivity rate. The manufacturing process in a pharmaceutical industry includes processing, manufacturing, extraction, purification, and packaging of the drug products. The manufacturing operation is divided into two major stages: the first step consists of the production of the active drug ingredient and the second stage consists of the transformation of the active pharmaceutical ingredient into the finished pharmaceutical drug product. The manufacturing of tablets involves different unit processes like milling, blending, granulation, drying, compression, coating, and packaging. With the use of IoT-based applications, the pharma industry is manufacturing clinically smart pills which are a significant sector of investment for the pharmaceutical industry. In pharmaceutical manufacturing, the IoT control system analyzes the whole chain of production lines to packaging of finished goods. The near surveillance helps the system to modify, eliminate lags, and remove unnecessary work. Sensors are the core of every device management, providing real process information and transmitting smart decisions to central network to ensure the quality of product. Each stage such as granulation, milling, coating, and packaging is validated when the stage is undergoing surveillance continuously. All environmental variables in a pharmaceutical process must be monitored, to maintain a product quality which is possible only by monitoring of production. IoT plays a significant role in tracking the real production quality from a distant using smart devices and sensors. Environment is a key factor that affects the production of pharmaceutical drugs. Therefore, to monitor the environmental conditions, IoT may be implemented. IoT aims to make the drug processing transparent with the use of real-time sensors. These sensors detect the info of environment parameters such as humidity, light, temperature, and exposure to radiation that can be regulated using intelligent devices. To avoid loss because of these environmental factors, an alert may induced. IoT sensors can be used to ensure the product quality. The information gathered by the sensors helps to understand the status of various stages of product development cycle. The details include the raw resources used, changes in temperature, disposals, and transportation. The quality of the product depends solely on the real-time monitoring under which the quality of the product is confirmed. Product quality is preserved with IoT-based pharmaceutical applications which monitor the production processes. Quality control is a pivotal and significant step in the pharmaceutical industry [15].

Necessarily, there are two leading roles that IoT performs in pharmaceutical manufacturing. First, it helps in connecting the "Things" that make the product-machines

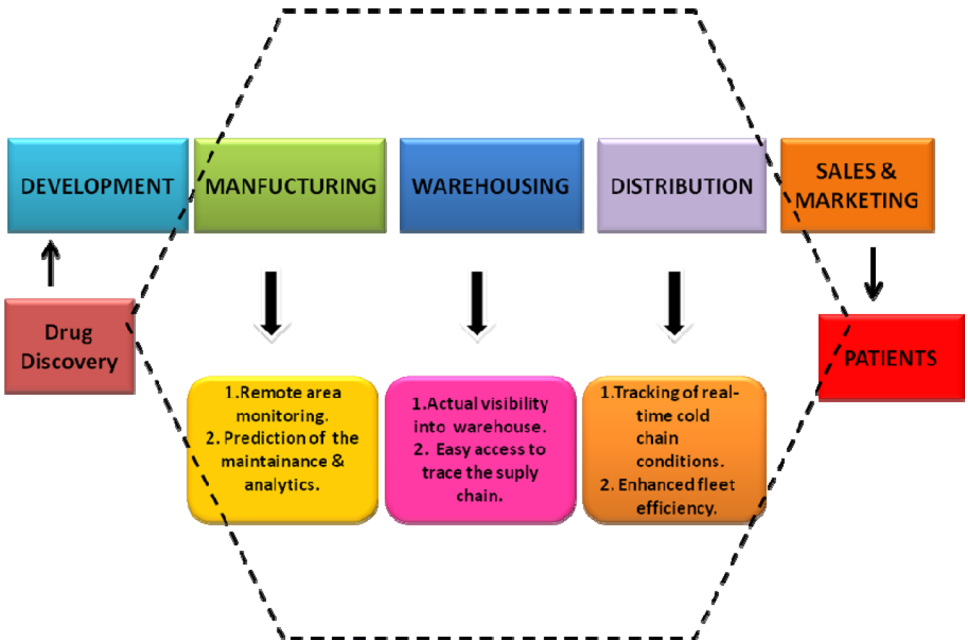

Fig. 2 IoT application in different pharmaceutical processes across the value chain

and equipment to make the manufacturing processes execute more efficiently. This role is usually played by the sensors and analog-to-digital converter (ADC), though in a limited way. Alternatively, we can tap into data that are being gathered or are induced by the products, making the products "smart" and feasibly utilizing that data for the interest of the customers and building up the business. IoT-based technologies could be directed for connecting and controlling the pharmaceutical equipment, networks, and systems to enhance the supervision control, data acquisition, and standardization of processes [16]. With the use of sensor-based information, it helps the engineers to build self-learning predictive models and provide diagnostic facilities throughout the company's equipment portfolio—improving efficiency, durability, or reduced intervention in the supply chain as discussed in Table 1. Moreover, by gathering real-time information about the use of equipment, calibration and its quality allows the manufacturing team to make informed decisions maximize equipment efficiency, minimize downtime and increase resource allocation, lowering the production costs and reducing cycle times.

The promising benefit of IoT in pharmaceutical manufacturing could be reduced production costs, real-time monitoring and control, optimization of pharmaceutical unit operations and enhanced patient outcomes [14]. IoT-based manufacturing control systems have been defined as supervisory control and data acquisition system, manufacturing execution system, manufacturing data, and distributed control system. These systems are helpful for monitoring and controlling the manufacturing activities to enhance the quality of the product.

IoT in Warehousing

In pharmaceutical industries, warehousing is a critical area. For assuring a constant and timely flow of the pharmaceutical products, pharma companies have storage/warehousing facilities in different parts of the country. Having the warehouse operations in-house may be a deliberate step by most of the pharmaceutical industries, as most of them opt to supervise their warehouse operations and storage conditions internally, provided the nature or character of their products. According to McKinsey study, warehousing costs for 95% of pharma logistics costs; therefore, warehousing is an expensive commerce [17]. It is quite a strenuous task to track products in the warehouse and make comprehensive utilization of operators and the transport equipment without having any real-time visibility into the activities.

The application of IoT in warehouses enhances the effectiveness and accuracy of the warehouse processes such as stock-taking, product sorting, and inbound and outbound. This optimizes the operation and improves the level of warehouse service. The overall management and supervision of warehousing activities can be accomplished using WSN technology, RFID technology, and the wireless video monitoring systems. RFID technology efficiently increases the identification rate of products and performs monitoring and product control when used in inbound and outbound activity. As soon as the stocks or storage devices containing RFID tags pass through the region with RFID readers, the readers will be able to read the data and send the data to the control systems. To reduce the travel distance, labor cost, and picking distance during inbound and outbound operations, Zhou et al. [18] carried out the pallet positioning with the use of RFID technology. This also allowed the receiving system to trace the position of products and other

Table 1 Methods to increase manufacturing efficiency and suggested IoT solutions

Business requirement	Methods	IoT solutions	Advantages
To enhance the manufacturing efficiency	By reducing the downtime of the equipment	Whole operational data and status (run time, temperature load, and ready to use/in operation/under cleaning/under maintenance) are gathered using smart equipment	Real-time dynamic scheduling for the shop floor processes
	To permit the visibility around the equipment for planning and scheduling of operations	Gathering real-time information on the data to predict the equipment downtime status	More efficient utilization of the equipment
	Promoting automatization for incident-related queries	Sensors are added for collecting data and information using industrial IoT platforms	Reduced downtime of the equipment
	Lowering the variability and improving the yield		Tracking of the overall equipment effectiveness
			Both productivity and efficiencies are enhanced

information automatically. Lei et al. [16] suggested an Automated Guided Vehicle (AGV) positioning method which is based on RFID technology. It addressed the issue that AGV is not able to reach the assigned location for transporting supplies accurately. This mostly decreased the rate of error for product handling during the inbound and outbound. Xue et al. [19] combined the RFID application technology with automotive vision system for locating and identifying the products that are being supplied to the warehouse with the support of the robot. It has significantly increased the productivity of inbound and outbound activities. Li et al. [16] used an active RFID tag in conjunction with ZigBee to capture remote wireless data and zoned stock-taking for products, that obtained the position of products at the time of outbound and inbound [20].

IoT benefits the warehouse operations in the below-listed ways [21],

1. Tracking the Inventory at Every Step
   The IoT helps in connecting the pharmaceutical products from the time of arrival at the warehouse until the time of delivery to the customer. The IoT provides information relating to the expiration date, so that action could be taken and thus helps in preventing the loss related to the damage of the product. This will minimize wastage and spoilage of the product.
2. Vision Picking (With Smart Glasses)
   Vision picking is an augmented reality branch that permits operators to operate hands-free and effectively. This can increase store efficiency. With the use of smart glasses, the operators can see the order picking directions through a visual display. Because it is a wearable technology, it requires minimal training by the operators or workers of the warehouse, and no structural changes are required to be made at the warehouse.
3. Data Analytics
   As the IoT connects, all logistics, trends, and possibilities can be observed by the scheme. Moreover, with the help of real-time visibility, easy and quick reactions could be given to any changes in the market. Using the information that is presented by the IoT, areas that are not performing well in the warehouse can be easily recognized, and strategic decisions could be taken.
4. Automated Tasking
   Automated tasking is performed using drones. These drones can conduct the cycle counts at night and make the data available for the operators to re-evaluate in the morning. It will avert operational downtimes and minimize the cost that is related to having human workers, like labour, electricity, and time. Robotics facilitated through IoT assists in the picking and packing operations. Automation of the monotonous tasks helps in distributing human efforts elsewhere. Order inaccuracy and inventory can also be decreased.

In summary, smart warehouses can improve the efficiency and visibility of warehouses by relaying metrics and real-time information to the technicians and managers of the warehouse. As discussed in Table 2, sensors are installed in the storage area and stock items for interpreting and conveying vital information (product site and stock details) informing inconsistencies, such as misplaced products. With real-time exposure and 3D vision of warehousing events with accurate and descriptive data at their disposal, warehouse managers may track and monitor the storage of sensitive medicines in controlled areas and identify problem areas and allocate resources for issues concerning human intervention.

IoT in Supply Chain Management

Even though the pharmaceutical industry is closely associated with healthcare and medical research, production, supply chain and transportation are an essential part of this industry. Because of the special environmental requirements in which the pharmaceutical products need to be handled, the pharmaceutical supply chain has a few preferences and key points other than the usual supply chain network. The essential pharmaceutical supply chain consists of the following phases—Manufacturers—Retailer—Hospitals/Pharmacy—Consumer [22].

As far as pharmaceutical drugs and medical supplies are concerned, it is equally crucial that product specifications should not be altered during transition from manufacturing units to customers. In this scenario, remote monitoring and network analysis are the techniques used for visualizing transport and warehousing operations in real time. IoT is all set to transform the process of a supply chain with both revenue opportunities and operational efficiency. The operational efficiency includes Tracing the assets, Operator relations, Prediction and inventory, Connected fleets, Maintenance scheduling, and Revenue opportunities [23]. There are some objectives in the pharmaceutical supply chain that need to be accomplished:

1. Raw material providers must ensure that all raw materials and ingredients delivered to the pharmaceutical firms are tagged.
2. During the production phase, tags must be scanned and entered into the database.
3. The raw materials are assigned with a unique serial no. That contains information regarding the manufacture date and expiry date and instructions for consuming the drugs.

Table 2 Tracking of the products in the warehouse [21]

Business requirement	Method	IoT solution	Advantages
To raise the operational effectiveness	By optimizing the movement of warehouse goods	Sensors are employed on the product/holding items that transfer the information about product location Using RFID tags on the material handling equipment, product location, and movement could be traced A wireless reader will capture the data (volume, dimensions) that are transferred from the pellets as they enter	The goods and operators are more effectively utilized Increased productivity
Maintaining optimum storage conditions	Trace the storage condition of sensitive drugs	Environmental sensors accumulate the information in the warehouse temperature regulated area to monitor the drug's environmental conditions in real time The data from the active and passive loggers are matched with the thermostability tables to produce alerts in case of temperature deviations	Fewer chances of expiration of drugs due to temperature conditions
Orient the production and demand	The real-time information of the warehouse-to-production is fed	The data on the shipment movements are cumulated and inspected by the sensors–from warehouse to distribution, to production planning	The inventory is being optimized Stock-out conditions are reduced

4. The software company that manages the RFID system scans the tag information and converts it into the electronic pedigree format.
5. More data are fed into the electronic pedigree scheme as soon as the pharmaceutical product begins to move through the pharmaceutical supply chain [24].

The pharmaceutical supply chain and logistics encounter some major challenges which are discussed in this section and convincing IoT solutions are proposed. Theft and forgeries of drugs during transportation are a major concern for pharmaceutical industries. If the pharmaceutical industry is not able to avoid or prevent such fraud in the supply chain, they will face problem in conforming compliance with the regulations. Therefore, the visibility of the supply chain is very critical to the pharmaceutical companies. To ensure the safety of the consumers and to keep up with the regulatory rules, IoT solutions and IoT-based intelligent devices can be used. RFID tags with EPC (Electronic Product Code) are fixed to the medicines. And all the required details such as production date, expiry date, chemical composition, and safety instructions can be incorporated with these RFID tags or EPS-IS (the Electronic Product Code Information Service) database. As all the pharmaceutical's batches are linked to EPC code, the pharmaceutical company can use the EPC codes to update product information and query medicinal information. Real-time notifications of medicines can be sent to the concerned parties with the use of upgraded network of IoT devices [25]. RFID tags must be attached with each and every product and batch that will ensure their easy identification. NFC (Near Field Communication) sensors, RFID tags with smart labels, and 2-D bar codes could be applied for the packaging of pharmaceutical products. These IoT-enabled packaging will track the goods continuously to detect counterfeiting or prevent theft as products move through the transportation network. Sensors can be combined with the GPS-enabled vehicles to monitor any change in humidity, temperature, and pressure so as to maintain the quality of products until they reach the final destination. IoT software system tracks products at line level and delivers the information to the concerned inventory department that will help in planning and coordinating accordingly. It offers a straightforward insight into the material available, work progress, and the approximate date of arrival of new material. In addition, it reduces cost and optimizes the supply chain process [15]. Table 3 indicates the recommended IoT solutions for effective tracking of pharmaceutical products.

Managing the various difficulties of supply chain management, IoT presents new levels of supply chain adaptability, visibility, and agility [26]. The data that are generated by the smart objects are collected effectively, examined, and then

Table 3 Tracking of goods at every step [27]

Business requirement	Method	IoT solution	Advantages
To confirm the integrity of medication and track the product across the supply chain	The communication is bidirectional and product authenticity is ensured at each step	Use of RFID tags, 2D bar codes, and smart packaging Electronic circuits or chips used for packaging material to track products Whole packaging data are transmitted throughout the transport process	Digital footprints are available Packaging that is enabled with IoT helps in continuously tracking the environmental conditions in cold chains Assure product quality
Effective inventory costs among the supply chain partners	Improving the visibility into the product movement at each step	Use of RFID tags, 2D bar codes, and smart packaging Transmitters at warehouses detect the movement of the shipment, and they transfer it to the central location	More effective supply chain Ensures that the product inventory matches the demand The increased alliance between the partners of the supply chain

converted into valuable information. This offers prodigious visibility in all supply chains, with early alerts of the internal and external situations that require some improvement. Acknowledging these signals within the time can take up the supply chain efficiency to some new level. In pharmaceuticals industries, for the tracing of the consignments across the pharmaceutical supply chain, the packaging is the crucial and condemnatory parameter for the quality assurance of the product. The companies should follow strict guidelines regarding the product packaging and governing the way how the drug product is transported, administered, and being consumed by the patient or the consumer. The consignment and medicines can be traced quickly and accurately with the help of smart pharma packagings, ensuring that the supply chain is uninterrupted and is cost-effective. When the Internet of Things is executed to the process of packaging, it offers various benefits, including uni-directional transmission, tracking of the drugs, and technique for displaying the status. The use of IoT in packaging and supply chain is important in the market where counterfeit drugs are frequently entering to the value chain. Tracing the drug inventory movement at different steps could increase the productivity and will prove to be cost-effective [27]. To track each crucial step from manufacturing to dispensing in the pharmaceutical companies, 2-D bar codes, RFID tags, and smart packaging are used. The result is that a complete digital footprint is available [28]. Table 4 indicates the application and advantages of IoT based solutions for maintaining and monitoring temperature conditions during transport/storage of pharmaceutical products.

Controlling the Cold Chain Conditions

The manufacturers of pharmaceutical products engage with a variety of drugs; for instance, biologics, which may be highly susceptible to the storage circumstances. These are costly or big-ticket drugs. Such drugs have a more significant fraction of high worth active ingredients that have meagre shelf lives and have a minimum temperature requirement. Most of them must be retained at a temperature lower than 77 degrees Fahrenheit; a few require 35–46 degrees during the cold chain transport. These drugs are stable at ambient temperature, but they must be stored in containers with a moderate temperature to prevent any temperature change that may occur during transportation [28]. Nevertheless, yet the pharma companies continue to lose a million dollars due to spoilage of products from temperature alterations. Therefore, by assuring visibility across throughout the shipment of the supply chain using sensors, RFID tags and smart packagings can prevent losses due to spoilage.

Conclusion

Internet of Things is a novel paradigm that is achieving grounds for its useful application in pharmaceutical sciences in particular manufacturing, warehousing, and supply chain management. IoT has the potential of adding new aspects to pharmaceutical operations by enabling smart technologies for anywhere, anytime, anything, and any media communication. IoT is evolving a critical domain witnessing remarkable leap in the innovative use of technology in pharmaceutical operations for enhancing customer satisfaction value. The future of IoT-based systems in pharmaceutical sciences should be developed to provide safe, sustainable, and cost-effective pharmaceutical products. Big data management, temper detection and management, and counterfeit pharma products could also be the future areas of application of IoT-based technologies.

Table 4 Maintaining and monitoring temperature conditions

Business requirement	Method	IoT solution	Advantages
Retaining the quality of drug during transport	Examining the temperature of the t drugs which are stocked in the shipment to assure that their stability is within the specified range	By placing the environmental sensors inside the product packages that will continuously update the temp Using program sensors to automatically generate an alert signal if the vaccine storage falls out the specified temperature range	Reducing wastage of drugs due to temp fluctuation Confirming to regulatory conditions Maintain product quality and efficacy

References

1. Madakam S, Ramaswamy R, Tripathi S. Internet of Things (IoT): a literature review. J Comput Comm. 2015;3:164–73. https://doi.org/10.4236/jcc.2015.35021.
2. Atzori L, Iera A, Morabito G. The Internet of Things: a survey. Comput Netw. 2010;54:2787–805. https://doi.org/10.1016/j.comnet.2010.05.010.
3. Čolaković A, Hadžialić M. Internet of Things (IoT): a review of enabling technologies, challenges, and open research issues. Comput Netw. 2018;144:17–39. https://doi.org/10.1016/j.comnet.2018.07.017.
4. Mehta R, Sahni J, Khanna A. Internet of Things: vision, applications and challenges. Proced Comp Sci. 2018;132:1263–9. https://doi.org/10.1016/j.procs.2018.05.042.
5. Li S, Xu L, Wang X, Wang J. Integration of hybrid wireless networks in cloud services-oriented enterprise information systems. Enterp Inf Syst. 2012;6:165–87. https://doi.org/10.1080/17517575.2011.654266.
6. Wang L, Da Xu L, Bi Z, Xu Y. Data cleaning for RFID and WSN integration. IEEE Trans Ind Inf. 2013;10:408–18. https://doi.org/10.1109/tii.2013.2250510.
7. Ren L, Zhang L, Tao F, Zhang X, Luo Y, Zhang Y. A methodology towards a virtualization-based high-performance simulation platform supporting the multidisciplinary design of complex products. Enterp Inf Syst. 2012;6:267–90.
8. Tao F, LaiLi Y, Xu L, Zhang L. FC-PACO-RM: a parallel method for service composition optimal-selection in the cloud manufacturing system. IEEE Trans Ind Inf. 2012;9:2023–33. https://doi.org/10.1109/TII.2012.2232936.
9. Lee I, Lee K. The Internet of Things (IoT): applications, investments, and challenges for enterprises. Bus Horiz. 2015;58:431–40. https://doi.org/10.1016/j.bushor.2015.03.008.
10. López TS, Ranasinghe DC, Patkai B, McFarlane D. Taxonomy, technology and applications of smart objects. Inf Syst Front. 2011;13:281–300.
11. Rayes A, Salam S (2017) The internet of things from hype to reality. In: Things in IoT: sensors and actuators, Chap 3. Springer International Publishing AG, pp 57–77
12. Lee J, Bagheri B, Kao HA. A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manuf Lett. 2015;3:18–23.
13. Bonomi F, Milito R, Zhu J, Addepalli S (2012) Fog computing and its role in the internet of things. In: Proceedings of the first edition of the MCC workshop on Mobile cloud computing. pp. 13–16
14. Thoben KD, Wiesner S, Wuest T. Industrie 4.0 and smart manufacturing—a review of research issues and application examples. Int J Autom. 2017;11:4–16. https://doi.org/10.20965/ijat.2017.p0004.
15. Singh M, Sacchan S, Singh A, Singh KK (2020) Internet of things in pharma industry: possibilities and challenges. In: Emergence of pharmaceutical industry growth with industrial IoT approach. Academic Press, pp 195–216
16. Li W, Kara S. Methodology for monitoring manufacturing environment by using wireless sensor network (WSN) and the internet of things (IoT). Proced CIRP. 2017;61:323–8. https://doi.org/10.1016/j.procir.2016.11.182.
17. Mc Kinsey Global Institue. The Internet of Things: mapping the value beyond the hype. San Francisco: Mc Kinsey and Company; 2015.
18. Zhou JR, Zhang HJ, Zhou HL. Localization of pallets in warehouses using a passive RFID system. J Central South Univ. 2015;22:3017–25.

19. Xue Y, Liu H. RFID-based intelligent storage and retrieval systems in automated warehouse. J Softw. 2011;6:1844–50. https://doi.org/10.4304/jsw.6.9.1844-1850.
20. Tejesh BSS, Neeraja S. Warehouse inventory management system using IoT and open source framework. Alexandria Engg J. 2018;57:3817–23. https://doi.org/10.1016/j.aej.2018.02.003.
21. Ding Y, Feng D (2018) Intelligent warehousing based on the internet of things technology. In: Proceedings of the 2nd international conference on advances in artificial intelligence 51–55 ACM. https://doi.org/10.1145/3292448.3292461
22. Chamekh M, El Asmi S, Hamdi M, Kim TH (2017) Context-aware middleware for RFID based pharmaceutical supply chain. In 2017 13th international wireless communications and mobile computing conference (IWCMC). pp. 1915–1920
23. McFarlane D, Sheffi Y. The impact of automatic identification on supply chain operations. The Int J Log Manag. 2003;14:1–17. https://doi.org/10.1108/09574090310806503.
24. Angeles R. RFID technologies: supply-chain applications and implementation issues. Info Syst Manage. 2005;22:51–655. https://doi.org/10.1201/1078/44912.22.1.20051201/85739.7.
25. Marathe A, Awwad M (2018) Internet of Things: oppurtunities and applications in pharmaceutical manufacturing and logistics. american society for engineering management, international annual conference
26. Phase A, Mhetre N. Using IoT in supply chain management. Int J Engg Tech. 2018;4:1303–2395.
27. Tajima M. The strategic value of RFID in supply chain management. J Purch Supply Manage. 2007;13:261–73. https://doi.org/10.1016/j.pursup.2007.11.001.
28. Ruiz-Garcia L, Lunadei L. Monitoring cold chain logistics utilizing RFID. Sustain Radio Freq Identif Solut. 2010;2:37–50.