sustainability

Review

Application of Internet of Things (IoT) in Sustainable Supply Chain Management

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Abstract: The traditional supply chain system included smart objects to enhance intelligence, automation capabilities, and intelligent decision-making. Internet of Things (IoT) technologies are providing unprecedented opportunities to enhance efficiency and reduce the cost of the existing system of the supply chain. This article aims to study the prevailing supply chain system and explore the benefits obtained after smart objects and embedded networks of IoT are implanted. Short-range communication technologies, radio frequency identification (RFID), middleware, and cloud computing are extensively comprehended to conceptualize the smart supply chain management system. Moreover, manufacturers are achieving maximum benefits in terms of safety, cost, intelligent management of inventory, and decision-making. This study also offers concepts of smart carriage, loading/unloading, transportation, warehousing, and packaging for the secure distribution of products. Furthermore, the tracking of customers to convince them to make more purchases and the modification of shops with the assistance of the Internet of Things are thoroughly idealized.

Keywords: sustainable supply chain management; Internet of Things; smart supply chain; smart distribution

Citation: Khan, Y.; Su'ud, M.B.M.; Alam, M.M.; Ahmad, S.F.; Ahmad (Ayassrah), A.Y.A.B.; Khan, N. Application of Internet of Things (IoT) in Sustainable Supply Chain Management. *Sustainability* **2023**, *15*, 694. https://doi.org/10.3390/su15010694

Academic Editor: GuoJun Ji

Received: 6 November 2022
Revised: 29 November 2022
Accepted: 7 December 2022
Published: 30 December 2022

1. Introduction

The systematic process of managing the flow of operations from acquiring raw materials from suppliers, manufacturing products, and distribution of manufactured goods or services to retailers for onward submission to end customers is termed a supply chain. Supply chain management, as depicted in Figure 1, is further elaborated as the right item intended for the right customer at the right price under the right condition at the right place and time in the right quantity [1]. However, this ideal condition has never been realized and is confronted with real supply chain problems of delivery delays, overstocking, and stock out [2].

Over time, the supply chains are getting riskier, more complex, and costlier which is against the main theme of the subject. Hence, to make it more convenient in the face of the growing challenges of new world orders, the involvement of information and communication technology has become a necessity [3]. In this connection, infrastructure relevant to the chain of supply needs to be intelligent and integrated. It can be materialized by combining products, services, operations, data communication, electronics, and computer science into a single platform to take full advantage of engineering, technology, and business [4]. Values can be added to the existing infrastructure of manufacturing by employing smart tools and equipment, analytics, and business intelligence [5]. With the emergence of commercialization and globalization across the globe, it has become mandatory for firms to have an advantage over their rivals to survive in a highly competitive market. Numerous examples are set to exist as smart versions of home, agriculture, city, and health.

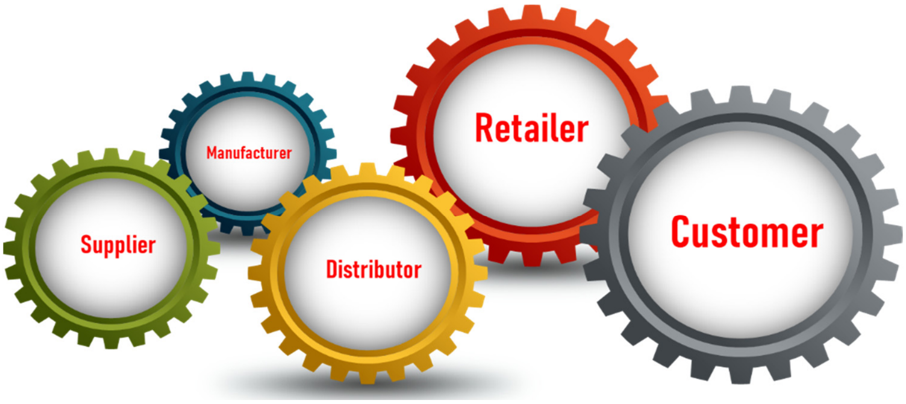

Figure 1. Supply chain management process.

In this context, various efforts have been extended to ensure the management, transmission, collection, and further predictions are intelligent to identify the cause and effect of disruption by real-time data analytics. By implementing advanced digital technologies, such as fog, edge and cloud computing, data analytics, and penetration of Internet of Things technology, it is possible to resist disruptions and recover in hostile conditions to provide seamless connectivity [6]. Moreover, digitization of the supply chain will assist in building a resilient manufacturing system and also in mitigating the risk of a war-like situation in a pandemic [7]. Furthermore, the resilience of the firm can be enhanced through suppliers, manufacturers, and customer integration. Additionally, the role of digitization in supply chain management is boosting the functional coordination and the downstream and upstream of supply chain integration [8].

This research article aims to provide necessary insights about the Internet of Things for the efficient and effective management of the supply chain. The paper is structured as follows. In Section 2, features of IoT are discussed. Section 3 gives a comprehensive overview of technologies applied in IoT. In Section 4, the application of IoT in manufacturing and distribution is thoroughly deliberated. Section 5 details the retail industry, Section 6 provides challenges of IoT, and Section 7 concludes the paper.

2. Features of Smart Supply Chain Management

The Internet of Things is an integrated system of intelligent interconnections fused with wireless sensory networks, big data, and cloud computing. The number of connected objects has surpassed the total population of the world, according to studies conducted by Cisco [9]. Immense numbers of opportunities are generated with the assistance of billions of smart objects of the Internet of Things [10]. The emergence of IoT technologies has revolutionized traditional society to a new horizon of information and interconnections. The term, IoT, was first devised for the presence of RFID that was later on used for embedded systems implanted for the fulfillment of special purposes in the physical world to redress problems or increase efficiency [11]. The role of IoT in supply chain management is unforgettable as it has enabled real-time monitoring of every stage of the chain to provide seamless movement of goods and information [12]. The first application of IoT in the supply chain was to identify and track items with the help of sensors and hand-held devices to control the flow of physical objects and information [13]. The decision process in the supply chain has been significantly improved due to an unprecedent amount of information generated in big data for processing. Hence, it has resulted in quicker and more efficient decisions being made. Traditional problems associated with the supply chain are replaced with newer problems of technology, system, and business modeling. The cost of ICT and smart equipment has been reduced due to excessive applications in other fields as well. The following are three core characteristics induced in supply chain management due to the integration of IoT.

2.1. Intelligent

Most of the organization's decisions will be taken by machines without the involvement of human beings. These decisions are comparatively fast, in real-time, and maintain room for future predictions. The intelligence in the system is accompanied by simulation and modeling capabilities and perform the assigned task as predict-and-act [14]. This feature is greatly assisting executives in trading off repetitive work.

2.2. Interconnected

The entire network of IoT has gained interconnectivity at unprecedented levels ranging from suppliers, manufacturers, and distribution to delivery of items to customers through smart gadgets. Interconnectivity in some cases is replaced by collaborations even at the global level that broaden the scope of business operations [15].

2.3. Instrumented

The visibility of IoT based-supply chain systems is more prominent compared to traditional systems due to generations and processing of real-time data acquired from sensors, actuators, GPS, and RFID tags at each distinct stage [16]. In this particular scenario, human involvement in monitoring and tracking products, services, trucks, and containers is significantly reduced.

3. IoT Technologies

3.1. Wireless Sensor Networks (WSN)

Sensors networks are spatially distributed systems of wireless communication connected by smart objects, transceiver modules, analog-to-digital converters, processor storage units, and power sources [17]. It works based on fluctuating current levels according to information received from the environment. Varying current conditions are converted from analog to digital for efficient processing. Numerous sensor nodes routinely integrate the data to the base station for onward submission to the end user [18]. Despite the small size, the capabilities of sensing, communicating wirelessly, and processing is exceptional. Primarily, wireless sensory network (WSN) was the technology of choice for the military; however, a wide range of applications are utilizing this technology nowadays. As far as industrial and logistic applications are concerned, the role of the sensory network is considered imminent. The main reason is the real-time environmental monitoring and safe handling of packages during distribution. WSNs are meticulously integrated with a comprehensive system of supply chain management. Prominent features of WSN in transport industries are the provisioning of high-quality and low-cost services during the deliveries of items from suppliers to manufacturers for processing, distributors, retailers, and end-users. Additionally, numerous environmental conditions, such as temperature and humidity, are required to be controlled for foods and medicine items while traveling to long-distance destinations [19]; thus WSN, as shown in Figure 2, is considered an excellent choice. Moreover, cold chain logistics have the added advantages of the WSN modeled in the ZigBee ad hoc network. The goods intended for delivery to remote locations are implanted with GPS and connected with a cloud service platform for real-time monitoring.

3.2. RFID

The term is frequently used for two types of devices, the reader (master of communication) and the tag (associated electronic cod). The reader propagates the RF signals, and tags receive identification codes through implanted sensors. Tags can either be powered by a battery or attain the energy from the RF signals of the reader. Numerous applications of RFID include security, asset identification, actuation, and user interactions to interact with centralized IoT systems. These are categorized as analog or digital types; however, they provide a variety of sensing applications, particularly in IoT system. The analog RFID system, although low-cost, experiences a serious trade-off between communication and sensing requirements. In contrast, digital RFID systems are immune to ambient interactions; however, generating precision with selective output at the cost of heavy energy consumption is practiced [20,21].

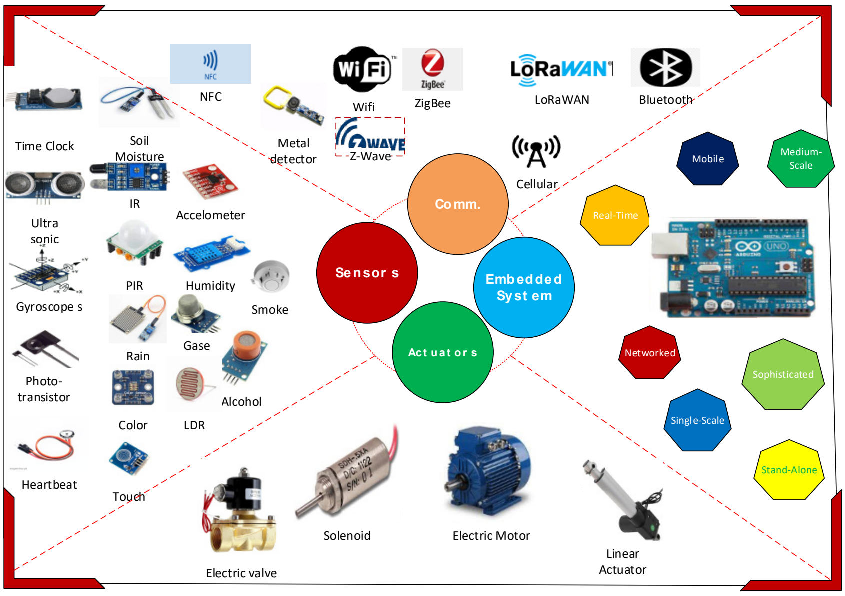

Figure 2. Components of smart sensory networks.

3.3. Middleware

The volume of data (structured, semi-structured, and unstructured) generated from IoT devices strictly depends on the number of surrounding devices; hence, a great numbers of events are consequently covered. The middleware layer, as drawn in Table 1, operated between the application and operating system to arrange a hidden translation. This function as a plumber integrates two applications; however, data is fed from the database. Different vendors are operating different middleware platforms to provide support with different underlying technologies. Multiple functionalities are controlled by the middleware, such as data storage and management, device interactions, analytics, security, and processing [22]. Platform in this regard must be specific to meet the requirement of the system. Four different types of middleware platforms are:

Table 1. Categories of Middleware in IoT.

Middleware	Features
Open Source	It provides data management services without any licenses, e.g., Thing-Speak and Kaa.
General Purpose	It can easily be connected with Arduino and Raspberry Pi, e.g., Temboo, Carriots.
Publicly Traded	It is developed and maintained by large corporations, e.g., IBM Watson, Microsoft Azure, AWS, Oracle.
End-to-End Connectivity	It is designed based on hardware, e.g., Particle cloud and Samsara [23].

The middleware for IoT must adopt the basic features to perform predefined functionalities, for instance, availability and stability to provide continuous service (24X7). This capability is sometimes vital in medical care facilities to monitor the patient's health around the clock. However, in the case of the smart industry, limited hours can be observed. Different pricing models are considered by vendors, such as pay for storage, pay as executed, pay as per connected devices, and subscription based. AWS charges for storage or execution. In contrast, Microsoft Azure collects bills for the number of connected devices and traffic of messages. IBM Watson charges based on data storage. Nevertheless, ThingSpeak and Kaa are open sources and offer free services for personalized applications, while Tembo and Carriots apply subscription-based services. In a scenario of support of hardware, Arduino and Raspberry Pi are customized boards to run IoT-based applications with various features and standards. These boards are provided with different built-in features of clock speed, RAM, processors, price, GPU, and support for different languages supports [24]. Keeping in view of the security requirements, various algorithms are applied according to applications. Numerous protocols control the functionality of IoT as per application requirements. For example, CoAP is comparatively lightweight versus HTTP and appropriate for mobile applications; however, MQTT is more suitable for limited bandwidth applications. Moreover, data may be obtained either through real-time streaming or historically to conduct analytics, such as Oracle, Google, Azure and Microsoft which offer real-time streaming options [25].

3.4. Computing Platform

Over the Internet, it aims to provide hosting services on the concept of distributed software architecture. New markets and communities have come into being due to cloud computing concepts, and remote computers are fed from data centers located in far-flung areas of the globe [26].

The role of a cloud platform is promising due to its immensely easy storage service, and vendors are taking advantage by providing subscriptions at hourly rates. IoT devices' data are stored directly on to a cloud computer leading to the new concept of a cloud of things that provides benefits in term of storage and computational resources. The introduction of the cloud platform expands the broadening of services to the real-world environment. This ecosystem is comprised of three services, as depicted in Figure 3. Firstly, the sensory network collects data from the surrounding environment about the physical world. Secondly, the storage, processing, and analysis of data are performed in the cloud environment. Computational and storage functions are conducted on virtual machines installed on physical servers in the cloud. The third vital component is the application running on a smartphone or computer. Visualization of results and issuance of necessary commands are executed by end-users.

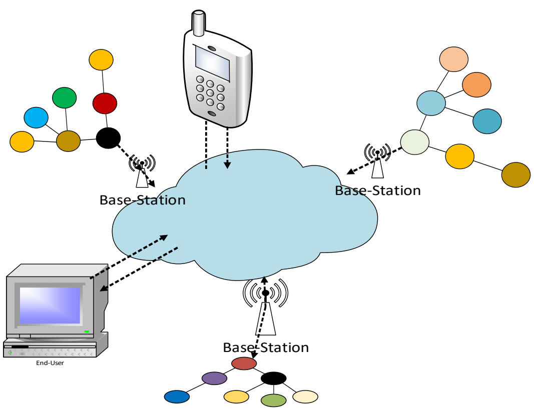

Figure 3. WSN-connected cloud platform of IoT.

4. IoT-Based Supply Chain Management System

The journey of a smart supply chain management system ranges from the provisioning of raw materials from suppliers, intelligent production of products at the manufacturing site, and secure and intelligent carriage of products under a strict monitory system. These products are transported to a retail store to provide to end-users, as demonstrated in Figure 4. Customers are further tracked down through a fully connected IoT system to monitor their behavior.

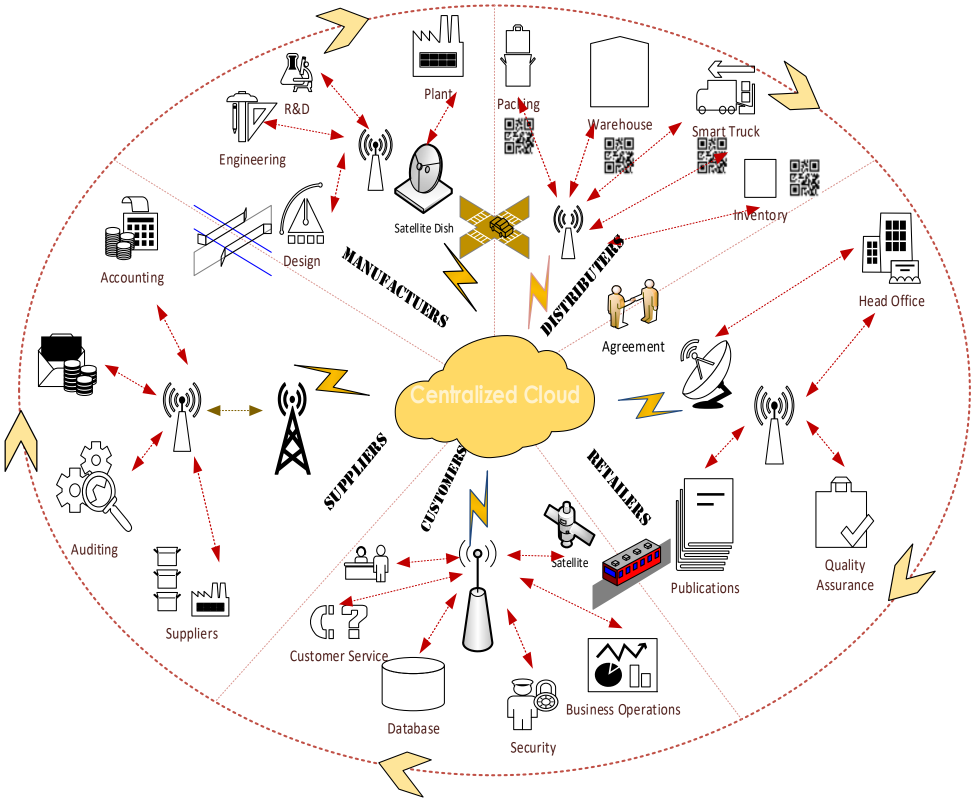

Figure 4. Smart IoT application in supply chain management.

4.1. *IoT-Enabled Manufacturers*

The modern world economy has been revolutionized by the occurrence of two important phenomena, regionalization and globalization. In this connection, major changes have been observed, not only on the economic side but also on the cultural, social, and political spectrum of society. Additionally, complexity, unpredictability, and competition also appeared to increase. The market is strongly involved in reshaping traditional products and services. It must produce high-quality products in the shortest period with low costs and environmental protection. This is not possible without bringing about changes in the production process to make it efficient, flexible, and transparent, shortening the process cycle, and increasing innovation. In this context, industries have to be updated on IoT, artificial intelligence, distributed databases, 3D printing, cloud computing, advanced robots, augmented reality, and autonomous vehicles. The IoT virtual network is created with the help of integrating products, processes, objects, workers, and systems that ensure communication in real-time [27]. The industrial environment is properly maintained based on the collection, processing, and dissemination of information and achieves the benefits shown in Figure 5.

In addition, other benefits are planning and monitoring of the production process, saving of raw material and human labor, a decline in downtime, manufacturing process efficiency, availability of real-time system information, improvement of transportation and logistics, the introduction of quasi closed loop production, production of refined products, implementation of an innovative ecosystem, and enhancement of attractiveness of jobs and activities. RFID and sensors are mandatory components of modern technologies in the implementation of smart factories. Several automation processes related to factories ranging from inbound and outbound management to identification of tools and parts are critical activities performed on the mentioned technology [28]. Primarily, the application of the technology was to identify and track the items in the logistics and retail sector of the supply chain; however, maximum benefits can be obtained in the manufacturing sector as well [29]. Similarly, cloud computing is providing on-demand service to furnish flexibility, reduce costs, and increase efficiency and revenue to smart factories [30]. Cloud platforms extend computational and storage capabilities that can be enhanced on demand. In this context, a huge amount of data generated during the operation of sensing devices of IoT are transported to cyberspace for conversion into useful information.

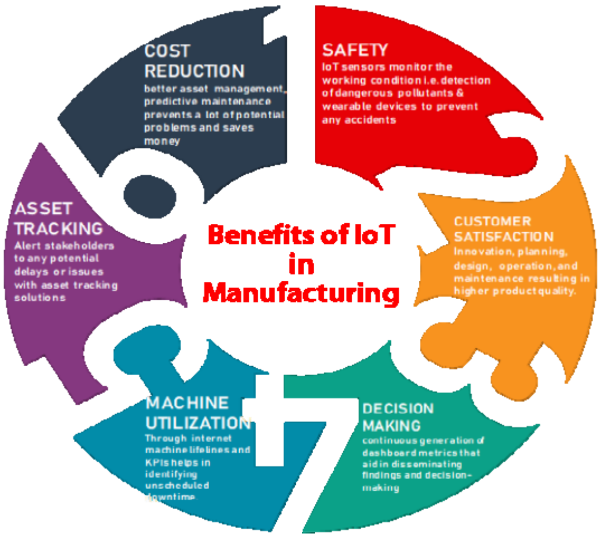

Figure 5. Benefits of IoT-based manufacturing.

As a result, the optimization and management of systems are conducted by big data analytics [31]. Cognizance about the running process inside the factory at different levels is disseminated from the wireless sensory network. A comprehensive IoT system, as shown in Figure 6, is installed with vibration sensors that issue warnings for preventive maintenance whenever its value exceeds the normal limit [32]. Similarly, low-cost but high-speed communication is performed through Wi-Fi, Bluetooth, and WiMAX in a smart factory.

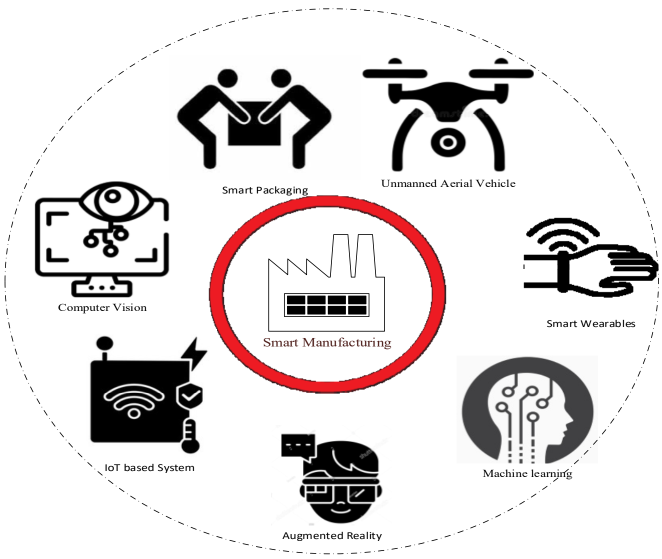

Figure 6. Smart Industry and manufacturing.

4.2. IoT-Enabled Distributors and Retailing

4.2.1. Smart Transportation

The efficiency of transportation can be improved by the strict monitoring of vehicles, cargo, and safe driving. Further added advantages are reduction of costs and cargo loss. In the context of vehicle monitoring, it is necessary on the part of the company to trace its location in a real-time scenario. Additionally, the speed of a vehicle, fuel consumption, and tire pressure are remotely observed. A full-fledge vehicle-tracking system was used to monitor the location (global positioning system) based on geographical coordinates, and the status of the vehicle has been updated in the database system [33]. By implementing a data analysis system, tracking the density of the vehicles and traffic congestion with the help of Bluetooth technology have been proposed [34]. Another attempt was made to develop intelligent logistics systems through the integration of AI, IoT, and 5 G technology [35]. The status and location of cargo can be monitored in real-time with the incorporation of 3G, GIS, RFID, AI, and middleware for data communication, signal acquisition, and processing of information [36]. Furthermore, data about the cargo rerouting, localization, and monitoring of its conditions are automated without the intervention of human beings. In addition, the systems are capable of communicating with each other and the centralized location [37]. Another application of IoT in the context of smart transportation is to monitor the driver's health and behaviors. The physiological condition of the driver was remotely tracked through low-power wearable WSN which has significantly helped to reduce roadside accidents by taking certain preventive parameters [38].

4.2.2. Smart Warehousing

With the emergence of continuous changes in technology and business operation practices, warehousing is becoming complex and critical, while considering the optimization of space, observing the warehouse environment, and bringing improvements in the process of product management. The logistic control system is optimized based on ZigBee technology that has taken the structure of star control [39]. The warehouse is properly managed by the IoT-based system with the application of data analytics and computational techniques. Strong management tools of the enterprise resource planning system help in dynamic inventory, quick in and out warehousing, and better management of products. The integration within the smart house is mainly possible with a short-range communication system, and ZigBee is considered the technology of the choice.

4.2.3. Smart Loading and Unloading

For the distribution of items, the loading and unloading process, storage, and stacking are required to be smart for efficiency enhancement, a speedy operation, and lower costs. Automation of forklifts with the smart technology of a RFID reader can greatly help to determine the exact position and further delivery of goods inside the warehouse without human intervention [40]. Similarly, robots are programmed and connected to the Internet to work as a bridge for warehouse keepers. Autonomous robots are supervised by the operator by giving sketch or speed commands from handheld devices.

4.2.4. Smart Carriage

High efficiency and low costs are possible by including AGVs in the internal and external transport of packages in the warehouse [41]. Numerous wireless technologies are utilized for communication among AGVs in the smart factory. The precision and accuracy of AGVs are ensured by implementing key impact factors, such as circular magnetic field and contour in the automatic logistic workshop [42].

4.2.5. Smart Packaging

The traditional approach to packaging has significantly changed to intelligent, interactive, and aware packaging with the emergence of IoT technology. Tracking and tracing of packages have improved incredibly on the introduction of smart packages that make decisions on the fly. This approach has further mitigated the menace of product recalls. Smart labels fixed on packages are machine readable with sensors attached to the system using Bluetooth, RFID, and NFC [43]. To take full advantage of smart packing product design and automate the packaging system, a wireless sensing device of IoT is implanted on it. High flexibility, velocity, and real-time exchange of information are ensured with the help of an advanced robotic system. This is further interlinked with cyber networks and shaped in the form of the automated e-fulfillment system [44]. The same technology and implementation of NFC has been adopted to categorize the products based on temperature sensitivity [45]. Package design is incomplete without utilizing an appropriate application, for example, to determine the condition and effective monitoring of packaged food items. Particularly, storage and transportation is controlled by a customized platform [46]. Likewise, iMedPack is an intelligent pharmaceutical packaging system fitted with passive RFID suggesting a promising solution for the safe delivery of medicine. The system is installed with a built-in automatic reminder system that gives an alert in case of non-compliance with pre-set conditions [47]. Short-range wireless technology of IoT systems is the technology of choice to determine its recognition and readability. Presently, NFC and RFID are mainly utilized in IoT; however, with the advent of new techniques and procedures, real-time monitoring will greatly improve packaging quality.

4.2.6. Smart Distribution Processing

This refers to a set of processing performed at a logistic center or warehouse before the shipment of products. To create ease and enhance added value, the products have to pass through sorting (arrangement of products into sets) and labeling (affixing labels). Products are divided based on their types and invoices to improve delivery support. Sorting is accomplished through an autonomous-wheeled robot to perform a roving survey in offices, manufacturing units, and libraries that travel in a close spacing of 6 cm [48]. For efficient management of warehousing logistics and the meticulous process of picking with the assistance of fast localization of storage items, the system utilizes minimum cost of maintenance technology and long-range application [49]. The label is incorporated with the required information about the product to make it more traceable and enhance the value-added service in the logistics sector. In the food industry, for cold chain monitoring and real-time traceability, the smart labeling tags are connected with a microcontroller that can be extended to humidity, light, and temperature sensors and can be used as an antenna assembly for RFID communication to track food items [50]. In the context of the product distribution process, the use of RFID is frequently extended to long-range technology to remotely conduct sorting and labeling.

4.2.7. Smart Distribution

IoT has a strong involvement in the distribution sector of supply chain management to add value for intelligent management of the center. The distribution of products can be made smart with the inclusion of networking, flexibility, intelligence, digitization, and intelligence. In this context, smart distribution centers are erected with automation and intelligence features for handling and sorting equipment. An IoT-based integrated route planning system is comprised of genetic algorithms and planning techniques to route food distribution at multi-temperature [51]. As far as the intelligent delivery of goods is concerned, the health of goods and time precision approach for delivery cannot be guaranteed without implementing the emerging technology of unmanned aerial vehicles, autonomous vehicles, and intelligent containers [52]. The latter item consists of a wireless sensory and communication network to disseminate information about the autonomous process. Necessary information regarding environmental conditions, type of loaded items, and transaction information, such as costs, order transport, and impact of traffic situation, are provided to the end-user remotely [53]. This results in a more comprehensive, easy-to-use, and up-to-mark supervisory system being developed.

5. IoT-Based Retail Industry

The retail industry, as given in Figure 7, has witnessed immensely high competition that can only be beaten by the introduction of innovative solutions. To efficiently run a retail store, engagement with potential or current customers is vital to establish new connections or increase purchases from existing ones, respectively. This arrangement can be made either inside the store over applications on smartphones or the Web. The in-store encounters can significantly be improved by utilizing IoT-enabled gadgets. The camera network extends from an IoT system designed for in-store use to determine and analyze the employees and customer behavior and inventory management [54]. This network is responsible for analyzing the entrance and exit patterns, visit frequency, duration of visit, and interactions of the customers with sales people. The store layout is accordingly modified to increase the flow of customers and mobile marketing. Local servers are installed in the store based on these patterns so personalized offerings are made on screen or engaged with Chabot. Furthermore, customer-specific information collected based on facial recognition is fed on social network sites and new offerings are made [55]. Another option is to track the shopper during a purchase from the store and establish the relationship through a mobile payment method via the wireless network. This option is comparatively cheaper than the camera network; however, it is inadequate to learn more about overall customer experiences and behaviors. Customers who intend to shop are offered Wi-Fi connectivity invitations by retailers to be followed. In case shoppers decline to use Wi-Fi service, they are still tracked unless their smartphone Wi-Fi is turned off. Cisco, Apple, and Starbucks in Korea provide cloud-hosted portals to predict customer behavior and path visualization. Likewise, customer buying behavior is followed based on credit cards whenever scanned for payment at the point of sale [56]. This is considered the cheapest option to track the shopping habits of the customer. IoT devices are an integral part of the advent of printable RFID tags that are not required to be removed at the POS.

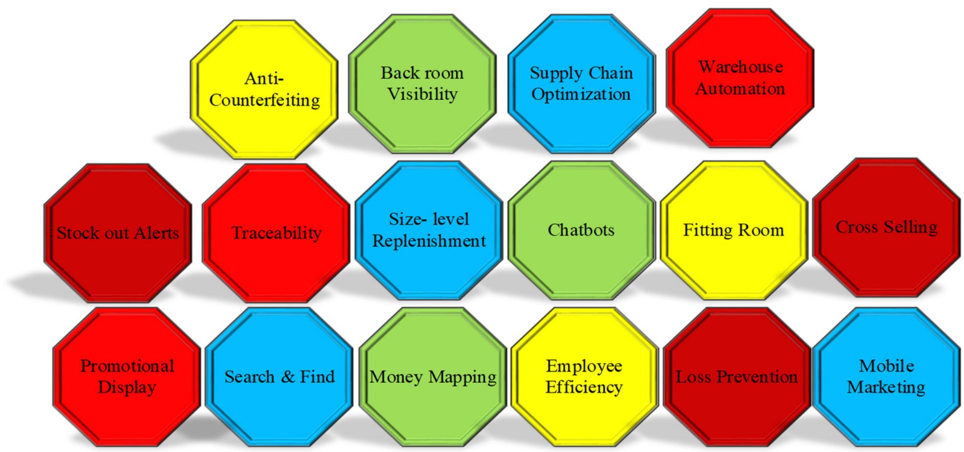

Figure 7. Benefits of IoT in the retail sector.

Moreover, these tags are included with detailed information about shoppers and the store. To further enhance the customer experience and track the location of products, the items are affixed with sensors that are connected through optical communication, Wi-Fi, ZigBee, Bluetooth, and ultra-wideband. The efficiency of logistics is increased with the enhancement of tracking capabilities both at storage and transit from the distribution center to the store or warehouse [57].

6. Challenges of IoT in the Supply Chain

The IoT-based supply chain is confronted with numerous financial and environmental challenges. The higher cost of smart gadgets, especially RFID, does not allow the penetration of technology into the open market [58–60]. Similarly, the design and prices of controlling software systems for the smart operation of the process are considered big hurdles in the prevalence of the Internet of Things in the supply chain. However, the issue has been partially countered by connecting the transducers of IoT networks with mobile devices providing versatility and availability. In the context of the environment, the challenge currently faced by IoT devices is the lagging traditional design of sensors and actuators increasing e-waste. The advent of smartphones in the open market with multi-functionalities is introducing green technology [61–63]. Serious efforts in this regard would help in the revolution of IoT in every field of life.

7. Conclusions

The adoption and integration of IoT have demonstrated social, economic, and environmental on-the-ground benefits. The entire supply chain has been transformed as flexible and dynamic with high quality and low cost at delivery of service. This paper provides due understanding to supply chain policy makers and managers and helps proceed into the industrial revolution. Packaging of manufactured products prepared to be carried to the distribution center need more accuracy and precision. In this context, excessive use of supply chain-based sensory networks, RFIDs, and bar codes is an effective solution that can further be integrated with the distribution center for early preparedness. On the distribution side of the supply chain management system, strict monitoring of cargo and vehicles and safe delivery of items to the distribution point and updating the location record can significantly reduce the loss. Moreover, smart warehousing is critical for space optimization and continuous improvement in product management. IoT-based integrated systems of warehousing, loading, and unloading can reduce operational time with enhanced efficiency. The store layout is accordingly adjusted and modified to increase the frequency of customers and guide them to purchase more from the store. Purchasers are further tracked by collecting customer-specific information through Wi-Fi technology. IoT is considered an effective technology in the future that would revolutionize the existing industry and households. Moreover, the connected gadgets will be data-driven and highly responsive with a strong feedback system. The technology will pave the way for personal autonomy and energy efficiency with minimum waste.

Author Contributions: The original draft of this endeavor of research was designed and prepared by Y.K. However, the definition of methodology and supervison of research has been provided by M.B.M.S. and M.M.A. Moreover, formal analysis and curation fo data has been conducted by S.F.A. Last but not least, N.K. and A.Y.A.B.A. have been keenly involved in investigation, visualtization and writing—review and editing of this research work. All authors have read and agreed to the published version of the manuscript.

Funding: This article processing charge (APC) is funded by Multimedia University, Malaysia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We acknowledge Multimedia University, Malaysia for providing the funding for this research. We also acknowledge the role of Middle East University, Amman Jordan as significant in this research.We would like to appreciate the contribution in terms of technical support of Iqra National University, Riphah International University, Institute of Business Management, and University of Chakwal.

Conflicts of Interest: No potential conflicts of interest were reported by the author.

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