


Review

Impact of Internet of Things (IoT) on Inventory Management: A Literature Survey

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Abstract: *Background:* The advancement of Industry 4.0 technologies has affected every aspect of supply chains. Recently, enterprises have tried to create more value for their businesses by tapping into these new technologies. Warehouses have been one of the most critical sections in a supply chain affected by Industry 4.0 technologies. *Methods:* By recognizing the role of inventory management in a supply chain and its importance, this paper aims to highlight the impact of IoT technologies on inventory management in supply chains and conducts a comprehensive study to identify the research gap of applying IoT to inventory management. The trend and potential opportunities of applying IoT to inventory management in the Industry 4.0 era are explored by analyzing the literature. *Results:* Our findings show that the research on this topic is growing in various industries. A broad range of journals is paying particular attention to this topic and publishing more articles in this research direction. *Conclusions:* Upgrading a supply chain into an integrated supply chain 4.0 is beneficial. Given the changes in fourth-generation technology compared to previous generations, the approach of conventional inventory replenishment policies seems not responsive enough to new technologies and is not able to cope with IoT systems well.

Keywords: supply chain management; inventory management; Industry 4.0; Internet of Things (IoT); warehouse management; smart warehouse



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1. Introduction

As an essential part of supply chain management (SCM), inventory management is that it is related not only to manufacturing, but also to pricing. The objective of managing inventory is to minimize the inventory cost by setting the right inventory replenishment policies with consideration of various factors to maximize the customer service level.

The very first motivation that caused us to write on this subject was the lack of a study that gathers all the work previously done on the applications of IoT and Industry 4.0 on inventory management. This study helps to better understand the core concepts in inventory management and opportunities in the advanced applications of Industry 4.0 in inventory systems and provides solid ground for future works by demonstrating the current needs and shortages in this particular area.

The scope of the study is limited to three major publishers which had the most contributions on the subject. We focus on three main keywords in the process of indexing the pervious works in our paper. This helps us to better focus on a specific domain and provide quality work on the subject.

This paper is organized as follows. Section 2 presents our survey methodology. Section 3 outlines the related studies about the impact of IoT on inventory management.

Section 4 analyzes the reviewed papers and presents the findings. Finally, Section 5 presents the conclusion and introduces research gaps and suggestions for further work. You can see the main contributions of the paper in the Figure 1 below.

- Conducted a holistic literature review about the impact of IoT on Inventory Management
- Identified the research gap of applying IoT to Inventory Management
- Explored the trend and potential opportunities of applying IoT to Inventory Management
- Suggested the future research directions of Inventory Management such as Sustainable Inventory Management, Green Inventory Management

Figure 1. Main Contributions.

1.1. A Brief on Classical Inventory Models

Inventory, which may contain raw materials, work-in-process (WIP) components, or finished products, is a significant part of the supply chain. Inventory costs account for a large percentage of the total supply chain cost. Inventory management aims to optimize inventory by planning and controlling inventory levels to reduce inventory cost and improve customer service satisfaction. The key research problem is how to answer two fundamental questions: “when” and “how many” order should be placed considering supply lead time, on-hand inventory, etc. To address these two questions, corresponding inventory models must be formulated.

In general, there are two types of inventory review in inventory management based on the approach to reviewing inventory: periodic review and continuous review. With continuous inventory review, inventory level must be monitored continuously. An order should be placed whenever the inventory level is less than a predetermined amount. The predetermined amount is referred to as the ordering point. The ordering quantity will be calculated based on the forecasted demand, holding cost, ordering cost, etc. The two simplest classical models with continuous inventory review are the EOQ (economic order quantity) model and the EPQ (economic production quantity) model. The EOQ model assumes the ordering quantity is received completely and immediately after ordering, while the EPQ model assumes the ordering quantity is received incrementally while the products are being produced.

1.2. Industry 4.0

There are two main streams of view about the Internet of Things (IoT) and Industry 4.0 regarding the terminologies and their use. One stream of view considers the terminologies “Industry 4.0” and “IoT” equivalent and usable interchangeably. Another stream suggests that IoT is a means of Industry 4.0 and that it can be referred to as an enabler to the concept of Industry 4.0 [1]. In this paper, we build up our study on the latter view and look for creative ways that IoT helps in Industry-4.0-related matters.

The idea of the Fourth Industrial Revolution (Industry 4.0) was first introduced by the German government. It marks a new generation of enhancing organizations’ performance with a set of technologies such as Internet of Things (IoT), RFID tags, Internet of service (IoS), cloud computing, big data, cyber-physical systems, etc. The First Industrial Revolution began with introducing the steam engine to industry. The transition from manual production to mass production raised new issues and challenges to deal with in industry. With the spread of electricity use in factories, the Second Industrial Revolution occurred.

The Third Industry Revolution came with the evolution of the electronic world and the advancement of information technology (IT). Industry 4.0 has brought new perspectives to all parts of a supply chain. With Industry 4.0, organizations could reduce waste, increase responsiveness, and perform real-time decision-making. Cyber-physical systems (CPS) are natural and human-made systems (physical space) which are tightly integrated with communication, computation, and control systems (cyberspace). The recent progress in and extensive implementation of sensors, data acquisition systems, computer networks, and cloud computing have made cyber-physical systems important infrastructure in various industry sectors.

On the other hand, the industry's widespread use of sensors and control systems has led to a huge volume of data [2]. Managing such a huge amount of data (known as "big data") needs specific consideration [3]. Cloud storage is used for this purpose. By analyzing demand data and enabling self-decision-making algorithms for the machines in CPS, the production line can work efficiently with a minimum of direct human role and fewer errors in real-time interactions. With the use of these new technologies, occupational psychology becomes important and plays a significant role for the human force. Smart manufacturing is in place to create automation in an integrated system of CPS, which is will be more self-guided in dynamic decision-making and interconnection between machines.

The manufacturing section of supply chains has benefited from Industry 4.0, as do all other sections of the supply chain, such as the distribution section, transportation section, etc. Industry 4.0 technologies have affected various industries, e.g., aerospace, agriculture, construction, food and beverages, pharmaceuticals, services, etc. There are many opportunities available for sustainable manufacturing in the context of Industry 4.0 as well. The digital cyber network is the key to sharing information in the closed-loop supply chain to make manufacturing sustainable. Products and processes should be eco-friendly and take into consideration closed-loop life cycles through re-use and remanufacturing.

To apply Industry 4.0 technologies in practice, organizations require specific infrastructures that are able to bring new innovative business models. New business models, including "disruptive business models", are needed in a complete digital area to provide smart goods and services to customers. The idea of the extension of Industry 4.0 would be realized by automatic virtual metrology, which can reach the zero-defect goal in automation and extend to Industry 4.1 as the next phase [4]. Although the Industry 4.0 concept has been paid much attention in different fields, the implementation of Industry 4.0 has not yet been broadly realized in practice successfully [5]. Moreover, IoT-based supply chain systems are not widely studied from academic and industrial perspectives either.

1.2.1. Internet of Things (IoT)

Internet of Things (IoT) was coined by one of the executive directors of the Auto-ID Center. The idea of network devices has led to the idea that machines could work dynamically as an integrated system without the interrelated interference of a human interface which may lead to errors or time wasted. This method of making the machines smart machines introduces a pictures of manufacturing and production systems, like the smart factory. The IoT driver receives much attention as one of the Industry 4.0 modules in this idea. It is a robust communication between the physical and digital world used in different areas to make goods, operations, and services smarter in the value chain by offering new potential solutions to alter their functions. Internet-based wireless technology connects all the devices together for interactions that lead to smarter functions. System awareness of the environment is also possible via sensors, where devices transmit a large amount of data in real time. IoT can have a significant effect on the supply chain in the effective use of resources, transparency and visibility of the entire supply chain, real-time management of the supply chain, optimizing the supply chain, and increasing agility of the supply chain [6].

1.2.2. RFID Technology Enabling IoT

RFID can improve the performance of the whole supply chain from warehousing to transportation through real-time communication and information sharing. RFID can improve inventory flow by increasing the traceability and visibility of products. RFID can help to reduce inventory loss and inventory misplacement and to limit transaction negligence and supply fault [7]. The terminology IoT was used first for defining RFID tags [8]. By connecting RFID readers to an Internet terminal, the items attached with tags can be identified, tracked, and monitored globally and automatically in real time. RFID is considered a precondition for IoT. RFID systems refer to a whole that includes components transmitting data. These components have extensive variety in shapes, models, and sizes. Their applications are slightly different from one another. However, the two main components, readers and tags, remain mostly the same. An RFID system may include one or more readers and tags.

The tags attached to the objects store their unique IDs. The readers send a recon signal to investigate their surroundings in search of the RFID tags and read their IDs. This proposes a solution that is useful in logistics, e-health, and security by providing a real-time map of the objects and therefore transitioning the real world into a virtual representation. RFID tags are very similar to adhesive stickers from a physical point of view. These tags are usually passive, meaning that they do not require any power to operate, and are triggered by using the signal from the readers, which induces power to the tag's antenna. The power is then utilized to supply the microchip located in the RFID tag, which will be transmit the ID stored in it. Conversely, there are two other kinds of RFID which rely on their own power supplies: semi-passive and active tags. Semi-passive tags use a battery to power the microchip that stores the ID. Semi-passive tags also use the power transmitted by the reader to transmit the data. On the contrary, active tags use battery power to transmit the data to the readers. These two types of readers can provide better coverage but come with increased costs [9].

1.2.3. IoT Applications

Noting the definition of IoT, its applications are broadly imaginable in many areas such as safety, security, sustainability, etc. In fact, the applications of IoT technologies are everywhere around us, such as smart homes, smart cities, self-driven cars, IoT retail shops, farming, wearables, telehealth care, hospitality, smart supply chain management, etc.

1.3. New Information from Industry 4.0 Brought into Inventory Models

In the past, suppliers had significant effect on production plans. Now, customers play the main role of defining demands. Thus, production plans should be adjusted accordingly. Analyzing data to plan production and optimize decisions for competitive businesses is necessary. Production rates need to be adjusted according to customer demand. The machines in the production line should work collaboratively based on the received demand. With change in demand, the production rate should be changed proportionally. To smoothen the production process, the inventory in the warehouse should be sufficient to cover continuous demand changes. Therefore, inventory replenishment policies, inventory review, and ordering quantities should match with changing demand.

By employing Industry 4.0 technologies, specifically IoT, which make devices connected work collaboratively and coordinately, inventory management should be more responsible for changing inventory operations due to the change in demand. Considering the smart factory idea in the Industry 4.0 environment and the fact that inventory management is the main part of SCM, inventory replenishment policies must be re-reviewed, and new principles for adapting the Industry 4.0 technologies must be developed [10]. As such, it seems unlikely that conventional approaches could provide the materials in the right amount with lead time and without shortage for the production or assembly lines. With all these considerations, we review the available literature on this subject.

2. Survey Methodology

The paper aims to conduct a holistic literature review about the impact of IoT on inventory management, identify the research gap of applying IoT to inventory management, explore the trend and potential opportunities of applying IoT to inventory management, and suggest future research directions for inventory management. In this study, a content-analysis-based survey was performed. The articles were collected from three bibliographic databases: ScienceDirect, Springer, and Emerald.

The keywords were categorized into primary and secondary keywords based on the articles conceptualized as Industry 4.0 in supply chain management. The primary keywords used for the initial search are matched to various levels of inventory management in the supply chain, whereas the secondary keywords reflect one of the most important technologies in the Industry 4.0 area, IoT, which impacts SCM. Table 1 illustrates the keywords used for our searching.

Table 1. Keywords.

Keywords	Details
Primary Keywords	Supply Chain Management (SCM)
	Inventory Management
	Supply Chain 4.0
	Logistics 4.0
	Warehouse Management
Secondary Keywords	Industry 4.0
	Internet of Things (IoT)
	IoT-based Framework
	Smart Warehouse

The first search was carried out using the primary search keywords and secondary keywords that appear in the titles or the abstracts or keywords of the articles. All articles are written in English, available in online databases of journals and conferences, and published by scholars and practitioners. With our search range between June 2001 and July 2021, we faced a limited number of available articles. The subject of this paper is relatively new and is still under development at the time of penning this paper.

Figure 2 shows the steps taken to scan all the retrieved papers. The selection criteria for our further scanning contain the four steps as follows: (i) Firstly, the collected articles were reviewed only in titles, keywords, and abstracts. (ii) Six papers were excluded because of technical problems—for example, because we could not access the full articles. (iii) The papers irrelevant to inventory management or IoT were excluded. The articles concentrating on marketing policies or production procedures were omitted because these articles are not linked exactly to the inventory management part of the supply chain. Moreover, the articles that only depict electrical devices and the physical-technical methods for implementation and other scientific issues were eliminated as they are not relevant enough to our literature review. (iv) Finally, 10 additional articles were added for our references from the three mentioned databases, plus 2 new papers from two different publishers of all pre-scanned papers. In total, a sample of 55 articles was reviewed in our study: 42 from Science Direct, 5 from Emerald, 6 from Springer, and 2 from others.

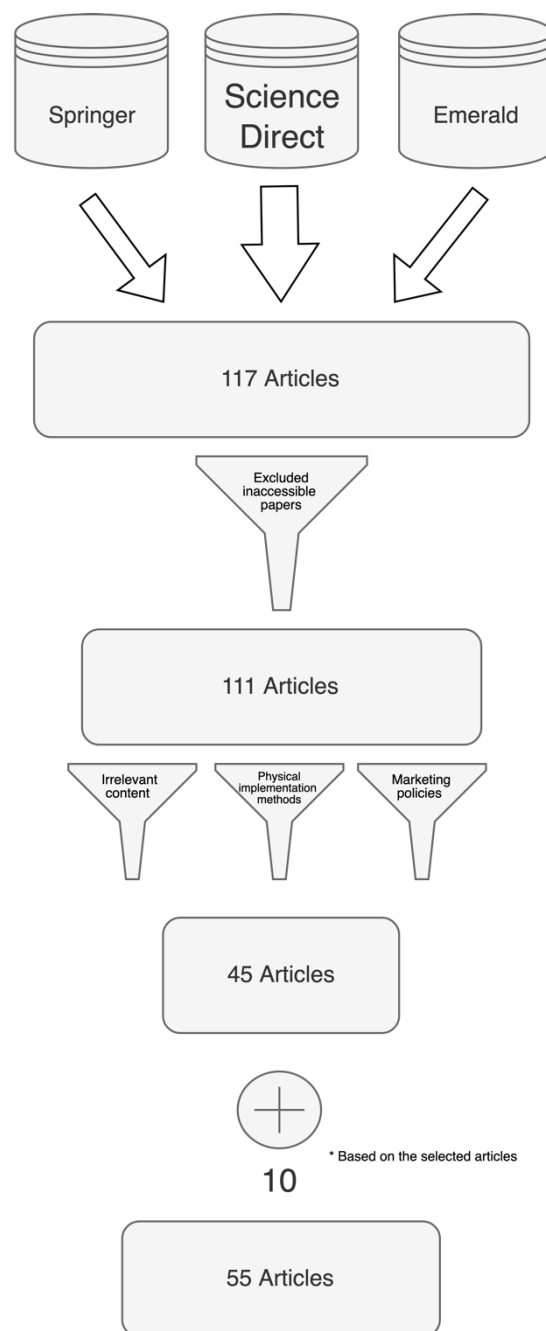


Figure 2. The systematic survey process.

3. Literature Review

The literature reviewed in the paper can be classified into three categories: initial preparation of IoT, structural implementation methods and requirements for IoT, and impact of IoT on inventory management in various industries.

3.1. Initial Preparation of IoT

With the advent of Industry 4.0 and its new technologies, the classic approaches in inventory management have been challenged. New inventory models and approaches must be innovated to determine inventory replenishment policies with the introduction of new technology.

Ref. [11] considered storage agent (SA) actions to reach the optimization goals of an automated inventory management system. This paper did not apply Industry 4.0

technologies for the aim of automation planning in this part of supply chain management (SCM). It compared the Markov decision process (MDP) with other conventional methods and used the MDP to deal with uncertain problems, including “busy storage place” and “misplaced product”. Ref. [12] proposed using IoT to track the location of components from a remote location. Doing so can improve the productivity and speed of shipment. It also provides an accurate status of warehouse stocks and automatically notifies the warehouse manager. By using RFID tags, intelligent warehouses can control the material flow both in and out, which leads to proper warehouse scheduling and highly intelligent inventory management [13]. The study by [14] suggested that using RFID technology in Inventory Management can cut down inventory inaccuracy by 20–30% so as to reduce the operation costs and shortage levels.

Some companies have established special projects targeting warehouse automation and control through industrial wireless networks (IWN). The study reported IWN advantages to include reduction of the labor force and increases in mobility and flexibility. Wireless communication technologies in a warehouse are able to organize thousands of goods in a specific space. Moxa use RFID and wireless networks to categorize its products in order to save working time and resources and prevent wire network limitations [15]. Each company has its own unique and particular solution for implementing Industry 4.0. In other words, the solutions and impact of Industry 4.0 would be different between different companies. Since Industry 4.0 technologies have not been well developed yet, significant investment and more research in this area must be carried out [16].

Ref. [17] introduced the key performance indicators (KPIs) to measure which specific areas of the supply chain are affected by the technologies of Industry 4.0. The analysis in the paper showed that order fulfillment is one of the areas which is the most affected by the introduction of Industry 4.0 through tracking products via IoT and RFID tags. More than 50% of the impact of the new technologies on this part of the supply chain certainly leads to opportunities, while the rest could be opportunities or threats, depending on the context of the implication. This ratio of certain opportunities is higher for warehouses—about 67%. Ref. [18] presented online optimization models and showed how they could help cope with real-time challenges. In practice, a time-dependent model can be of great relevance as it allows embedding inventory decisions. Ref. [19] acknowledged that IoT is able to achieve collaborative warehousing by using multi-agent systems, which increase the safety and security of the supply chain. Ref. [20] proposed a manufacturing transportation system via IoT enablers. The system is able to track finished goods and various related items along the supply chain.

Another usage of IoT in warehouses and inventory management is with the concept of zero-warehousing smart manufacturing (ZWSM). IoT-enabled infrastructures are required to achieve a level of visibility that makes the ZWSM concept possible [21]. By using IoT, the smart inventory replenishment system proposed in [22] relies on the point of consumption (POC) data that are gathered from the end customers by extending the vendor-managed inventory (VMI) to the end customers. Assuming that the manufacturer’s operational capacity is limited and that customer demand must be fulfilled, the system is designed to focus on inventory control, customer prioritization, and smart decision-making. The system showed that inventory replenishment decisions could be improved extensively. This system can generally enhance the service level and capacity utilization without adding to the customer’s inventory costs.

3.2. Structural Implementation Methods and Requirements for IoT

The study by [23] presented the principle and implementation methods of an automated warehouse management system (WMS) in a telecommunication company. This system contains a labeling line in the warehouse and uses Microsoft Visual Studio and barcodes to show the data of access, location, receiving, and expiry in order to enhance utility. The study concluded that the performance of the inventory management system

is improved in terms of the operational cost and accessibility of items. Furthermore, the system created extra space in the warehouse for the company.

Ref. [24] indicated that it is essential to use cloud and fog systems for data storage and processing in an IoT-based system when designing a smart warehouse monitoring and control system by using different components such as sensors, network gateways, actuators, etc. Ref. [25] proposed an implementation framework which requires RFID tags, Wi-Fi module (ESP8266-01), Wi-Fi development board (NodeMcu ESP8266-12e), and database (Raspberry Pi 3 as the data receiver and web server—programmed with the Python language).

Ref. [26] mentioned that smartphones can be used in industry to scan and record the data of RFID tags. Doing so would not only save more time, but also enhance inventory management functions. IoT provides real-time visibility and 100% inventory accuracy. This study proposed a framework for smart SCM where inventory is dynamically trackable to managers so that they can connect suppliers and orders in a timely manner via the integrated system. Ref. [27] used a new automatic code acquisition system which replaces the conventional way that a person has to check the inventory before entering the ERP system manually to barcode all the entries. Ref. [28] considered intelligent shelving and pallets as the force for driving innovative inventory management in the case of stocking in warehouses. With this system, tracking and tracing stocks in the warehouse would become faster, more precise, and safer. Ref. [16] presented a model to adopt industry 4.0 in inventory management. An intelligent system is able to measure inventory levels with an RFID shelf. Thus, it is feasible to control the material flow in a smart warehouse via mobile devices.

Ref. [29] discussed the item delivery problems that may be caused by delivery vehicle issues or item accumulation in the warehouse. By using IoT, a smart dispatch system which increases the transparency in the logistics system has been implemented, making visual management of the distribution system possible. In the study by [30], an IoT-based model for decision making in inventory management, which uses RFID, wireless sensors, and other middleware technologies at an enterprise level was introduced. Moreover, an information platform processes the information to ensure that inventory costs remain at their lowest.

The integration of Industry 4.0 technologies requires the various actors and stakeholders of the supply chain to ensure full collaboration and coordination among all stages of the value chain [31]. By recognizing the impact of integration within the whole supply chain on warehouse management systems (WMS), transporters will be able to communicate with the intelligent warehouse management system regarding the location and arrival time to have it select and prepare a docking slot and arrange the just-in-time and just-in-sequence delivery. RFID sensors will reveal delivery data simultaneously. They also send the track-and-trace data to the entire supply chain. WMS can automatically assign storage space according to the delivery specifications and request the appropriate equipment to move the goods independently to the appropriate location. When the pallets are moved to the particular location, the tags will transmit signals to the WMS to provide real-time visibility of inventory levels, which can prevent extra cost from out-of-stock situations and increase the management's ability to make decisions on the settings that might be necessary to increase customers' service level.

The study conducted by [32] demonstrated the possibility of using a warehouse equipped with heterogeneous RFID readers from different manufacturers which is not dependent on a centralized server. Such an implementation could reduce the initial implementation cost and investment. The real-time analysis of RFID efficiency was incorporated with indoor localization and navigation of warehouse mobile robots. With RFID and universal plug and play (UPnP) technologies, [33] recommended a new approach to manage production and logistics processes by turning a product into a smart object, which allows upgrading the products to intelligent objects and services that result in a high level of functional interaction. Using the concept of the industrial Internet of Things (IIoT), another

study mentioned a novel approach to the production of smart products and shaped the production line in order to minimize energy consumption [34]. Ref. [35] introduced a communication system in the supply chain for open communication with its electrical professional infrastructure and security to benefit from enhancing real-time properties. The basics of time-sensitive networks (TSN) were explained and compared with the Internet for this communication system. The communication between Industry 4.0 factories which are related or working in parallel or in coordination could be improved. Therefore, these factories can take advantage of the benefits of dynamic inventory aggregation and pooling. A new model in reducing production time, which affects inventory capacity management, has been proposed as well. The paper takes an artistic approach by integrating the fuzzy theory into its model, which results in an optimization in the trade-off between production time and the costs included [36].

Ref. [37] proposed the mechanism that enables objects to communicate via the web in the warehouse. The mentioned warehouse (full of various objects) is smart and works with a system that contains RFID sensors and consists of a data collection module and an administrative module. The paper also simulated and evaluated the proposed system in various scenarios in the context of discovery time, response time, and transmission failure. Its effects, as seen in the warehouse, are performance improvement, quick interaction, and high accuracy. Furthermore, the system was designed and created to be semi-automated. Therefore, with the absence of the user's decision-making, it can work properly. This advantage provides companies more flexibility to shift from their former systems to new technologies and start using the proposed system easily.

Ref. [38] introduced a solution for reverse supply chain management (R-SCM) which is dependent on a heterogeneous IoT network following digital security controls (DSC) objectives. Inventory management utilizes smart containers, while a LoRaWAN (LoRaWAN® is a LPWAN protocol designed to connect battery operated "things" to the Internet in regional, national, or global networks) context network is liable for checking the industrial facilities by using Bluetooth Low Energy (BLE) and RFID technologies. The four performance tests used to assess this system were data ingest, geographical spread, data size, and network latency. It was found that the testing results are proper for an inventory management setting. However, BLE seemed to be the bottleneck for larger arrangements. Ref. [39] proposed a warehouse management method using mobile robots, which are highly automated and flexible. When a number of such robots operate in the same environment, the challenge is how to manage them. This can be resolved through a cyber-physical system using IoT, which leads to finding a collision-free path for these mobile vehicles.

3.3. Impact of IoT on Inventory Management in Various Industries

3.3.1. Spare Parts Manufacturing

Ref. [40] proposed a smart inventory management system for two types of spare parts: consumable and contingent spare parts for a semiconductor manufacturing company. The system aims to prepare spare parts for the right machine at the right time with the right quantity through IoT technologies. It would lead to making better decisions and establishing transparency and flexibility between fabs and suppliers. Ref. [41] used IoT technologies in the aircraft spare parts inventory system to reduce inventory costs and unavailability risks. Improved fleet management and increased customer stratification were achieved. There are four types of IoT applications in the airline industry: in-house sourcing, ad hoc pooling, cooperative pooling, and commercial pooling. The paper reviewed these four types of applications by using the business model of the KLM Engineering and Maintenance Department. There are numerous challenges with managing inventories of maintenance, repair, and operations (MRO) spare parts. Ref. [42] applied big data analytics, machine learning, and IoT to predict maintenance cycles and spare parts needs. MRO spare part usage in the automotive industry showed the differences in patterns, lead times, and costs, which need to leverage Industry 4.0 technologies to help improve inventory efficiency.

3.3.2. Agriculture Products

For precision agriculture in the agriculture industry, IoT can be used to track detailed information from product production to transportation. It allows stakeholders to receive real-time information about inventory status. With IoT, cloud technologies can be implemented to support the agriculture supply chain [43]. The study by [44] on agriculture logistics suggested RFID-based technology in the agriculture industry. The paper explored the application of RFID in agricultural production and examined the system's efficiency.

3.3.3. Food Industry

The paper by [45] discussed smart inventory management in the food supply chain and used the survey and sequential pattern for prediction with the AHP method. The three factors were presented for measuring the function of the food processing and distribution system on quantity, frequency, and recency (QFR) to indicate the impact of being smart in the food industry. The study concluded that the system's performance could be improved up to 66%. Another IoT application in the food industry is to use an IoT-driven sustainable food security system in which inventory levels are monitored and tracked through the whole logistics process, starting from the farm and ending with consumers [46]. This can also help policymakers monitor food processing, storage, and delivery to end consumers while minimizing food losses in the supply chain by controlling temperatures and planning routines.

Halal food organizations should re-examine their ordinary inventories and influence new innovations. There are many IoT applications in the Halal Food Store Network (HFSC) [47]. The possibilities and opportunities need to be further explored for the HFSC. There are five main areas in which the HFSC can benefit: tracking food items, upgrading supply chain efficiencies, easier livestock management, validation of food's halal status, and observing halal accreditations. Ref. [48] expressed that for special products such as drugs and food, which need specific storage conditions, IoT-based alert systems are beneficial and can lead to more sustainability. Ref. [49] proposed a live IoT-based monitoring system for the food supply chain which shares the information with stakeholders. As an immediate result, the quality of prepackaged food increases. Another example of smart inventory systems in the food industry is the IP-enabled soft drink vending machines that benefit from an inventory system accessible over the internet [50]. It is feasible that by using this technology, one could locate their nearest favorite soft drink in a matter of seconds. This is one of the earliest applications of the internet in inventory systems, which leads to more advanced applications of IoT in warehouses.

3.3.4. Pharmaceutical Industry

The study on pharmaceutical supply chains illustrated that using Industry 4.0 technologies in communication leads to fewer errors in demand forecasting and the improvement of storage space usage in warehouses [51]. RFID can provide expiration date information, which is the main reason for drug returns, and accurately forecast the reverse flow of expired and near-expired drugs. Thus, in the reverse flow, which plays a significant role in pharmaceutical and other perishable product supply chains, information integration is able to reduce wastage and improve sustainability.

3.3.5. People with Disabilities

Ref. [52] introduced an IoT application for people with disabilities. In this study, it was mentioned that RFID via IoT-based inventory management in stores can help people with disabilities shop more easily.

3.3.6. Construction Supply Chain (CSC)

The benefits from RFID tracking implementation in construction supply chains were presented in [53]. The material handling process and inventory counting, searching, and organization in warehouses became more accurate and reliable. In addition to easier mea-

surable benefits, such as alleviating laborious material handling tasks, shipment reliability was improved and supply lead time was shortened in the supply chain.

The concrete stocking-related applications of RFID tracking, e.g., counting, searching, and organizing the inventory, would be most beneficial to the companies with warehouses of construction materials. By using RFID in warehouses, stock recording and balancing would be more accurate. Doing so would result in less out-of-stock materials and less excess stock. Industry 4.0 concepts and technologies have been introduced to the construction industry differently due to the fact that construction supply chains are usually project-driven, and their partnerships are temporary and constantly changing. Ref. [54] defined “proximity” as a concept of distance that can affect construction supply chains. Because of the specific situations at construction sites, delivery lead time and holding cost are the two major factors influencing the entirety of the construction projects’ performance. Using RFID can help with tracking and localization and can improve proximity dimensions by solving the problem of late and early deliveries. Eventually, it can lead to reduced inventory cost, more efficient on-way inventory, shortened lead time, and fewer damaged goods [55].

Another example of IoT-enabled material inventory at construction sites is the inventory of the construction materials attached with RFID tags. The RFID tags contain the relevant data of the materials, including the manufacturers, technical specifications, scheduled installation sites and dates, purchase dates, and more. The RFID system plays an essential role in material monitoring and control by using IoT at construction sites. Engineers and managers use portable readers to track material delivery, storage, installation progress, and changes. The data are then transmitted to the dynamic database, which allows real-time information sharing with other project teams [56]. The study by [57] suggested that real-time inventory management can facilitate the construction process. The suggested method is to use long-range RFID readers in the storage area which can track the product-specific information stored on the tag attached to the materials. Doing so would allow the RFID system to read and update the inventory database when the materials move into or out of storage. This can also help the workers to trace the right materials by using the tag data. One good example of using IoT in construction supply chain networks is the use of IoT-enabled devices, augmented reality (AR), and fuzzy-VIKOR-analysis-based inventory management for the construction projects in the China Pakistan Economic Corridor (CPEC) [58].

3.3.7. Retailing Industry

The quick response system is an application of IoT in the retailing industry. RFID facilitates this system by tracking products. It minimizes the backroom inventory and shelf shrinkage of products while improving store security and ability to analyze sales data [59]. The method of product shelf and sales floor bidirectional movements has been proposed by incorporating RFID into the model described in [60]. This model can account for misreading from the RFID readers and avoid the disadvantages of fully automatic inventory control by applying for a simple heuristic extension. An interesting application is the use of RFID tags in fitting rooms.

An example is a German department store in Essen which uses RFID tags on clothes. When clothes are brought to the fitting rooms, a smart mirror will show similar items and suggest complementary clothing choices or accessories based on the information saved on the tag. This system is used in combination with smart shelves [59]. A new model has been introduced to deliver information regarding supply levels from the retailer to the manufacturer using RFID tags which increase the accuracy of the orders based on the retailers’ demand based on machine learning [61].

A challenging issue mentioned in [62] is the fact that the inventory data supplied by the point of sale (POS) are sorted out after the sales are closed. It cannot precisely represent the data of the products on the shelves. Using RFID-enabled tags and employing a software agent, an integrated information system is able to overcome the mentioned issue. By being able to telecommunicate the client inventory level to the manufacturer, the installment of

an electronic device inside the containers improves the opportunity of just-in-time (JIT) pickups and reduces the chance of late or unnecessary visits to the client site by 50%, as the study [63] indicated. It can also help the supplier to coordinate shipments and rebalance the retailers' stocking positions. A new approach has been mentioned to maximize the profit of a specific retailer by promoting items that will be expired soon, which helps in sales, reducing inventory costs, and prevention of the loss of goods [64].

3.4. Companies' Preparedness for Applying New Technologies

Ref. [65] provided a conceptual framework for assessing sustainability in SCM, which enables companies to understand the preparedness for Industry 4.0 transformation. The framework contains five enablers—business-based smart operations, technology-based smart products, management strategy and organization, collaboration, and sustainable development—with 18 criteria and 62 related attributes. Inventory management was mentioned in two criteria of the framework, including IoT and logistics integration. The study pointed out that concepts such as monitoring, resource management systems, visibility on in-transit consignment, enabling information-driven decision-making, and location, status and allocations could be counted as important attitudes of inventory management.

3.5. New Environmental Insights Impact

Greening is the process of transforming usual activities into more environmentally friendly versions. Integrating environmental insights into supply chain management has important influences on total environmental and economic improvement, which leads to more sustainability in the whole supply chain. The study shows that a green IoT system can improve decision-making in the green supply chain (GSC) and, in the same way, in the green inventory management to achieve greater sustainability [66]. Industry 4.0 capabilities along the supply chain can affect each of the given dimensions. Such capabilities further influence the greening of supply chains [55]. A new methodology has been introduced which helps to significantly reduce carbon emissions, which results in an improvement of the inventory management system [67].

4. Analysis and Discussion

In this section, the findings will be discussed based on the descriptive analytics of the sample literature we reviewed. The sampling process collects 55 papers for our review. The distribution of the articles considered for the survey by publication years is illustrated in Figure 3.

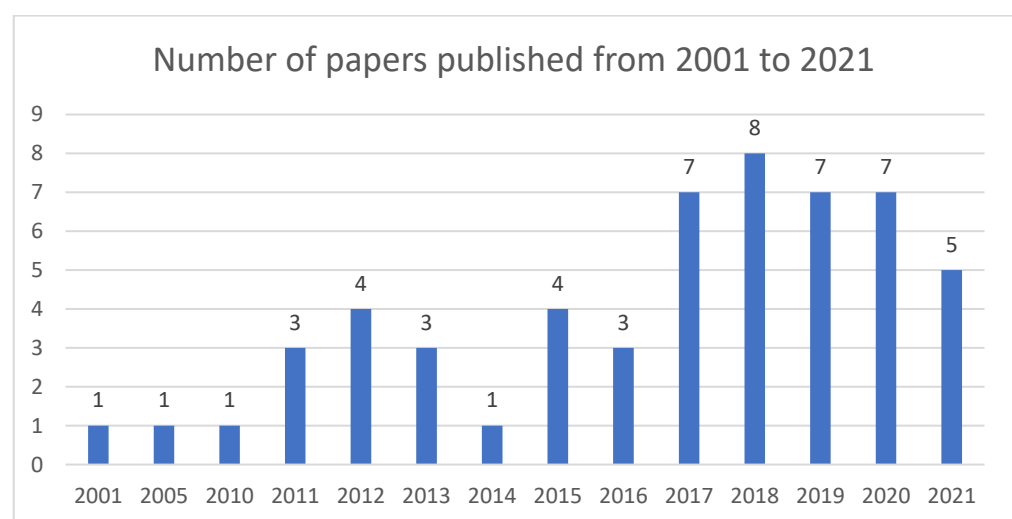


Figure 3. Distribution of the articles reviewed in the study by year.

The majority of papers were published over the last three years. The reason is that the keywords used by the authors to index the articles were relatively new concepts in the first decade of the 2000s. Thus, the research gap between the years 2001 and 2010 seems logical. Figure 4 shows that the interest over time has increased for the above-mentioned keywords around 2010, which supports the reason behind the unavailability of scientific work in the first years of the current millennium.



Figure 4. Interest over time for the keyword “IoT”.

Figure 5 shows the increasing interest in this topic over years. In terms of publication types, 11 out of the 55 considered articles in this study were published in conferences and 44 of them were published in journals, as shown in Figure 4. Table 2 presents the details of the journals and conferences we surveyed.

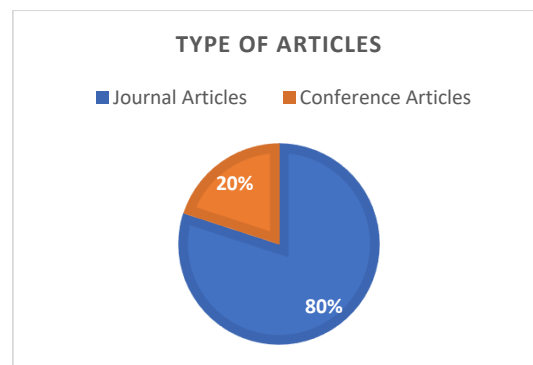


Figure 5. Types of articles.

Table 2. Journal and conference distribution.

Type	Title	Number of Papers
Journal	Advanced Engineering Informatics	2
	Alexandria Engineering Journal	2
	Annals of Emergency Medicine	1
	Automation in Construction Journal	2
	Automation in Construction Journal	1
	Cluster Computing	1
	Computers & Industrial Engineering	1
	Computer Communications	2
	Computers in Industry	4
	Computer Networks	1
	Decision Support Systems	1
	EURASIP Journal on Wireless Communications and Networking	2

Table 2. *Cont.*

Type	Title	Number of Papers
	European Journal of Operational Research	1
	Expert Systems with Applications	1
	Food Control	1
	Future Generation Computer Systems	1
	Industrial Management & Data Systems	3
	International Journal of Advanced Manufacturing Technology	1
	International Journal of Advance Research in Computer Science and Management Studies	1
	International Journal of Business Analytics	1
	International Journal of Production Economics	1
	Internet of Things	1
	Journal of Engineering and Technology Management	1
	Journal of Network and Computer Applications	1
	Journal of Management Science and Engineering	1
	Journal of Supercomputing	1
	Omega	1
	Process Safety and Environmental Protection	1
	PSU Research Review	1
	Resources, Conservation & Recycling	1
	Robotics and Computer-Integrated Manufacturing	1
	Sustainable Operations and Computers	1
	European Journal of Operational Research	1
	Wireless networks	1
	Total	44
	Number of journals	33
Conference	AASRI Procedia	1
	IFAC Conference	5
	Procedia CIRP—CIRP Conference on MANUFACTURING SYSTEMS	1
	Procedia Computer Science—Information Technology and Quantitative Management	1
	Procedia Engineering -International Conference on Engineering, Project, and Production Management Internet	1
	Procedia Manufacturing—Manufacturing Engineering Society International Conference	2
	Total	11
	Number of conferences	7

Since this is an emerging underexplored field of research, as shown in Figure 5, 38% of the chosen articles in this study focus on modeling and implementation methodology and principles. About 15% of the articles were on case studies, which could be investigated more. The case study articles present a rich vision of complex phenomena and help to develop theories further.

The percentages in Figure 6 indicate the topic is a niche for both practitioners and academic scholars to apply and improve theoretical methods in inventory management for different industries since it has not been implemented at an integrated level in most supply chains. The cross-sectional data collected by either literature review or surveys constitute 20% of the study. In terms of the conceptual framework, 7% of the articles focus on presenting the frameworks based on IoT systems. However, some literature reviews

provide frameworks based on the reviewed papers. The majority of the articles concentrate on modeling and introducing the platforms, and 20% of the articles contain analytical concepts and explanations.

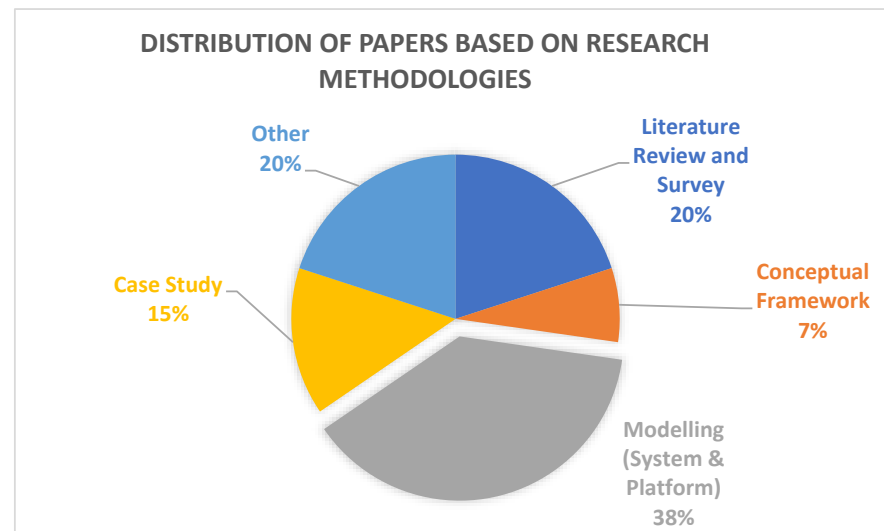


Figure 6. Research methodologies considered in the surveyed articles.

5. Conclusions

In this study, the impact of Industry 4.0 technologies, particularly IoT, on inventory management was investigated. Upgrading a supply chain into an integrated supply chain 4.0 is beneficial. Given the changes in fourth-generation technology compared to previous generations, the approach of conventional inventory replenishment policies seems not responsive enough to new technologies and is not able to cope with IoT systems well.

From the literature analysis, the trend and potential of IoT opportunities available in sustainable inventory management space were explored. Our findings show that the research on this topic is growing in various industries. A broad range of journals is paying particular attention to this topic and publishing more articles in this research direction. The systems and platforms that are applying the new technologies to the organizations are the major parts of this survey. Since each individual company needs its own specific solution for transformation to a greater high-tech level, this topic is expected to be addressed further in the future.

6. Research Gaps and Future Work Recommendations

To bridge the research gaps in the literature, the following are suggested.

- Considering sustainability in inventory management with a focus on the green supply chain as a whole to achieve more sustainability;
- Forecasting future customer demand based on data analytics and market intelligence while reviewing the product selling price and customer satisfaction to improve the accuracy;
- Reviewing suppliers' behavior by leveraging the available data and BI to know which supplier can provide the best quality, price, and response to last-minute orders;
- Establishing an integrative data-driven inventory optimization model instead of the conventional sequential approach by leveraging data about suppliers, customers, and inventory to maximize revenue and customer satisfaction;
- Using AR-enabled headsets to help workers improve storing and finding items inside an inventory and for training purposes;
- Optimization of the placements of items inside a storage facility by applying the results of data analysis from repetitive orders to minimize labor cost and improve efficiency;
- Improvement on decision making systems and lead-time delivery.

In Table 3, the application of IoT in inventory management have been classified in different industries. Based on the literature survey, we propose some future application of IoT technology in inventory management for the different industries discussed in Section 3.

Table 3. Application of IoT in inventory management in different industries.

Industry	Reference
Spare parts	[40–42]
Agriculture	[43,44]
Food	[45–50]
Pharmaceutical	[51]
People with disabilities	[52]
Construction	[53–58]
Retailing	[59–64]

Spare parts: For more risk reduction in maintenance operations and inventory of spare parts, IoT must be connected to cloud computing systems to enable decision support systems (DSSs) to predict orders of new spare parts based on the current rate of consumption.

Agriculture: Future works can enhance the application of IoT in agriculture product warehouses by enabling DSSs to indicate the amount and time and the type of the agriculture products for farming based on the characteristics of the product, such as volume, storage conditions, weather conditions, soil quality, and agricultural land. This would lead to more sustainable agriculture production with minimal waste, optimized use of natural resources, and less emission.

Food: This industry needs some structured frameworks for food product storage and transportation and to control and update the condition of vehicle conditions, such as temperature, humidity, etc. in real time. Additionally, the use of IoT connected to other Industry 4.0 technologies could help order delivery be more efficient based on capacity and the vehicle storage conditions needed for transportation.

Pharmaceutical: Improving the lead time of the delivery is one of the concerns that could be performed more effectively with more progress in use of IoT, especially in emergency situations.

People with disabilities: Establishing and introducing more efficient frameworks of smart houses and smart cities in practice is needed to meet the demand of people with disabilities for full use of smart systems.

Construction: One of the problems of construction sites is that inventory control is more challenging due to the nature of the work because of the lack of dynamically integrated warehouses. Therefore, future application of IoT sensors and equipment could upgrade inventory management for this industry by designing and implementing better sensor systems in the whole construction site, even while working and when the gradual use of resources takes place in different parts of the site at the same time.

Retailing: The use of smart shelves via IoT could progress to the level that refilling the shelves would be possible with the help of smart transportation or integration with robotics in the warehouse.

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