social sciences

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Impacts of Internet of Things on Supply Chains: A Framework for Warehousing

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Received: 29 January 2019; Accepted: 28 February 2019; Published: 6 March 2019

Abstract: The emergence of new digital industrial technology, known as Industry 4.0, has a positive impact on the performance of the supply chain. Warehouses are a basic part of the supply chain; they are used to store products and manage the inventory level. A sound warehouse management system can lead to cost reduction and also can improve customer satisfaction. Traditional warehouse management models have become less efficient and unsuitable for today's increasing market requirements. For the past decades, information and communication technology has been used for warehouse management. This paper presents a new approach for warehouse management by utilizing one of the main pillars of Industry 4.0, the Internet of Things. This new technology enables the connection of several objects through collecting real-time data and sharing them; the resulting information can then be used to support automated decision-making. The architecture of this application is illustrated and its potential benefits are overviewed. A framework is proposed to implement this approach in warehousing management, which can help in providing real-time visibility of everything in the warehouse, increasing speed and efficiency, and preventing inventory shortage and counterfeiting. This proposal gives an effective roadmap for enterprises to improve their warehouses by using the Internet of Things.

Keywords: Industry 4.0; Internet of Things; warehouse management system; supply chain

1. Introduction

The fourth industrial revolution can be described as "a shift in the manufacturing logic towards an increasingly decentralized, self-regulating approach of value creation, enabled by concepts and technologies such as cyber-physical system (CPS), Internet of Things (IoT), Internet of Services (IoS), cloud computing and additive manufacturing and smart factories" (Hofmann and Rüsch 2017). Applying the concepts of IoT and CPS to the manufacturing environment has led to the definition of Industry 4.0 that helps in developing smart production, smart products and smart services (Wollschlaeger et al. 2017). By shifting towards automation and computerized innovations, organizations can achieve more profit (Imran et al. 2018). One of the common definitions of the supply chain is, "A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves" (Chopra and Meindl 2013). It describes a collection of processes and resources needed to produce and deliver a product or a service to the customer from the start to the end. "Supply chain management (SCM) is the management of the interconnection of organizations that relate to each other through upstream and downstream linkages between the process that produces value to the ultimate consumer in the form of products and services. The main key of the success of any supply chain is to understand and satisfy customers' needs with the highest quality of products on time, that can be obtainable by eliminating non value-added activities, improving processes and making the supply chain more agile" (Kovács and Kot 2016). In most of the modern enterprises, regular supply chain processes are managed by software packages such as enterprise resource planning (ERP) and advanced planning and scheduling (APS). However, these systems are not enough to face the increasing challenges of today's supply chains; such as flexibility, responsiveness and agility (Reaidy et al. 2015). Hence, new approaches have been introduced to meet these challenges. With the imminent global shift towards Industry 4.0 and smart organizations, IoT technology is playing a vital role in this transition. The core concept of IoT is that "everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective" (Cortés et al. 2015). IoT infrastructure is based on many technologies such as radio frequency identification (RFID), Wi-Fi, Bluetooth, sensors, and cloud computing. IoT can be useful in improving the performance of the whole supply chain and transforming it to be a smart one; for example, it can be used for monitoring, tracking products, creating an intelligent transportation system, and demand forecasting. Inventory is a one of the significant areas where cost reduction can be achieved in a supply chain (Ibrahim et al. 2011). Specifically, IoT can reduce inventory costs as well as the bullwhip effect across the supply chain.

The main objective of this research is to study the economic and social impact of adapting Industry 4.0 and IoT technology in a warehouse , to show how it can help in saving money for any industrial organization and to show how it improves its performance by proposing in detail a theoretical framework of implementing IoT in a warehouse. The sub-objectives are to study the impact of Industry 4.0 on the supply chain and how it affects SCM functions, and to study the main components of the IoT application.

This paper is organized as follows. Section 2 gives a literature review about Industry 4.0, information sharing in supply chains and the previous research that integrates Industry 4.0 and IoT technology in supply chains. Section 3 illustrates the components of IoT infrastructure. Section 4 discusses the potential of implementing IoT in the supply chain, a conceptual framework for this implementation, and the expected challenges. Finally, conclusions are given in Section 5.

2. Literature Review

2.1. Industry 4.0 Key Technologies

The industrial sector acts as a key driver for the economic growth of most countries; for example, it accounts for about 80% of innovations and 75% of exports in Europe (Hofmann and Rüsch 2017). Industry 4.0 helps companies achieve massive gains in productivity, reliability, and efficiency in order to satisfy customer needs and hence gain more profit (Degryse 2016).

Industry 4.0 is based on four key technologies; the first one is CPS, an integrated system of communication, computing and control used for bringing together the physical and virtual worlds in many fields such as motor vehicle manufacturing, transportation, and logistics. The second technology is mobile internet and IoT technologies which help in making interactions between human and machines, and between machines to machines (make things able to talk), and can easily implement intelligent identification, location, monitoring, tracking and control. The third technology is cloud computing technology which deals with a computing a service over the internet with low cost and high performance and provides several internet services such as software, platforms, hardware and other information technology (IT) infrastructures. The fourth technology is big data and advanced analysis techniques which are used for processing different data types by using new processing methods to produce reliable information quickly, hence helping companies in decision making, improving processes, improving operational efficiencies and reducing costs (Zhou et al. 2015).

2.2. Information Sharing in Supply Chains

Information sharing has played an important role in supply chain management. Baihaqia and Sohal (2013) presented an empirical study to show the impact of information sharing on the supply chain. They found that sharing information between partners is necessary but not enough to achieve a significant improvement. The core is to focus on making supply chain partners more cooperative and to strengthen the internal integration between them by achieving tasks together so that the relationship between them is built on trust. Managers should identify the information to be shared and the best mechanism to share it, with the objective of improving the total supply chain performance. Choy et al. (2014) developed a hypothetical model with seven hypotheses to study the impact of adopting Information Technology (IT) applications in supply chain, such as information and communication technology (ICT), logistics information system (LIS) and business intelligence (BI). Two dimensions of service performance were taken into consideration; service quality for market-based view and competitive advantage for resource-based view. The results showed that most of the logistics service providers (LSPs) do not implement many techniques although recommended by several researchers, e.g., radio frequency identification (RFID). The proposed hypothetical model can be considered as a roadmap for LSPs to improve their competitiveness.

Grabara et al. (2014) illustrated the role and impact of information systems on transportation activities in the enterprise, such as improving the efficiency of the transportation process, better drivers' utilization, more efficient information exchange, and better financial results. They argued that without good information systems management, organizations will not be able to make sound decisions in transportation and hence will face risks in meeting market requirements. Jonsson and Mattsson (2013) used a simulation model to understand the value and impact of sharing four types of planning information (point-of-sales data, stock-on-hand data, customer forecasts and planned orders) on the inventory capital by using re-order point methods. It was found that the value of the shared information depends on whether the demand is stationary or not; when demand is stationary the stock-on-hand data has high value, while when the demand is not stationary the demand forecast and planned order data have high value. Sharing point-of sales has no value whether the demand is stationary or not, thus it is very important to decide how and when to share planning information. Vanpoucke et al. (2017) have developed an analytical framework to test how to take advantage of the integration between supply chain and IT for the operational decisions. Using IT has a stronger impact on the operational performance when used for upstream integration rather than the integration with customers. This can increase speed and accuracy and can improve delivery performance. However, according to Azab et al. (2016), many supply chains still suffer from miscommunication between different stakeholders and inefficient exchange of information. Hence, new approaches and techniques should be adopted to provide more efficient information sharing.

2.3. The Implementation of Industry 4.0 and IoT Technology in Supply Chains

With the emergence of IoT, researchers started to explore the potential of using this technology in several fields. Few studies addressed this implementation in the field of supply chain management (SCM). Imran et al. (2018) took a quantitative research approach with cross-sectional research design to study the impact of Industry 4.0's five factors (big data, smart factory, CPS, IoT, and interoperability) on the production and service sectors in Pakistan. They found that the five factors have a significant positive relationship with production and service sectors which means they have a great role in improving the overall performance. Jia et al. (2012) discussed the definition of IoT, its challenges and how it could be applied in different areas such as logistics and supply chain for tracking, tracing, monitoring and supervising. According to them, these applications enable real-time management of the whole system and hence make the supply chain more flexible and agile to adapt to any new conditions. Dhumale et al. (2017) studied the impact of implementing IoT across the supply chain, and argued that IoT contributes to the growth of the company and in facing today's challenges, it also had a positive impact on the company's future economy. Szewczyk (2016) studied the impact of IoT on the economy and society, and concluded that cloud computing and big data were the main elements that would act as powerful drivers for business innovation through developing a hyper-connected society. This will contribute to the growth of the worldwide IoT ecosystem and will be measured in billions of Euros in Europe alone. Manyika et al. (2015) analyzed more than 150 different use cases, such as health applications and industrial applications, to get a broader view of the impact of IoT on the economy. They estimated that IoT will have a potential impact ranging between $3.9 trillion and $11.1 trillion a year by 2025, which is equivalent to about 11% of the world economy.

Ng et al. (2015) addressed the impact of using IoT in SCM by developing a simple analytical framework. They illustrated how to translate the data collected by IoT into meaningful information to help the supplier/producer in managing the supply chain by choosing between two strategies. The first, tailoring strategy, stated that it is necessary to produce multiple product varieties in order to meet customers' demand. The second, platform strategy, stated that the supplier has the ability to produce standardized but flexible products that can be modified according to customers' demand. These two strategies can be more profitable through maximizing the customers' added value. In the field of agricultural supply chains, Yan et al. (2016) introduced an IoT-based model that used RFID to solve the problem of imperfect sharing of information. They also proposed two methods of information inquiry for static and dynamic information. These methods help the operators to easily track, trace and inspect products anytime and at any stage, which improves the authenticity and quality of the products and hence increases the supply chain efficiency. Cortés et al. (2015) reviewed some applications of implementing IoT in supply chains such as applying it to the agricultural sector, and emphasized its role in managing product information, reducing supply chain related costs, and improving the supply chain efficiency.

Reaidy et al. (2015) proposed an IoT infrastructure for collaborative warehouse order fulfillment based on RFID and a negotiation protocol which exploits competition and cooperation concepts between agents. An example of a collaborative warehouse was constructed to validate the proposed system and to analyze its impact on demand responsiveness with minimizing the fuel and labor costs. For decentralized warehouse management systems (WMS), this platform can improve warehouse visibility, traceability and transparency, thus it can improve the performance of the overall distribution processes. Li and Li (2017) provided a framework to show how IoT cloud could improve the SCM performance, especially supply chain innovation (SCI) by providing integrated data on activities, resources and processes which improves the overall performance of all the supply chain partners.

Qin et al. (2017) proposed an assessment model that showed the impact of using RFID on the problem of inaccurate inventory which occurred due to the bullwhip effect that results from information distortion through the supply chain. This loss in inventory leads to an increase in shortage and holding costs. The authors argued that utilizing RFID in the downstream transfer is more efficient than using it in the upstream stages. Tejesh and Roy (2017) developed an inventory management system based on IoT and open source hardware; it can be used for monitoring and tracking all the information about products, e.g., the location of an item in the stockroom.

3. Components of IoT Infrastructure

IoT is considered one of the main pillars of Industry 4.0 that helps organizations build and strengthen their competitiveness in the market and has a great impact on the modern economy transformation (Wielki 2017). Generally, the architecture of IoT has four basic layers: the perception layer, the transmission layer, the computation layer and the application layer. Each layer has inherent security issues connected with it. Figure 1 illustrates the components and function of each layer.

The perception layer, also known as the sensors layer, has a main function to identify, track and collect data from objects by using many technologies such as RFID tags, that are used to identify and track objects, wireless sensor networks (WSNs), and actuators that are used for monitoring and tracking the status of objects, then transmitting the collected data to the transmission layer.

The transmission layer acts as a link between the objects and the cloud; it provides data routing transmission through the network. Many protocols are used in this layer such as low-power wireless personal area networks (LoWPAN), which provide great connectivity with low energy consumption and self-organization, Zigbee, which is a wireless network technology that has the advantages of low cost, low energy consumption, low complexity, reliability and security, Wi-Fi, and 3G also can be used. The computation layer provides efficient and secure services to the transmission layer and the application layer. An interface technology is used in this layer to ensure security and efficiency of the exchanged data. Service management is also use, it is responsible for services like collection, exchanging and the storage of data (Lin et al. 2017). The last one is the application layer in which data is managed. It is very important to select the suitable protocol for managing the network. There are many protocols that can be used such as message queue telemetry transport (MQTT), advance message queuing protocol (AMQP), constrained application protocol (CoAP) and extensible messaging and presence protocol (XMPP) (Swamy et al. 2017).

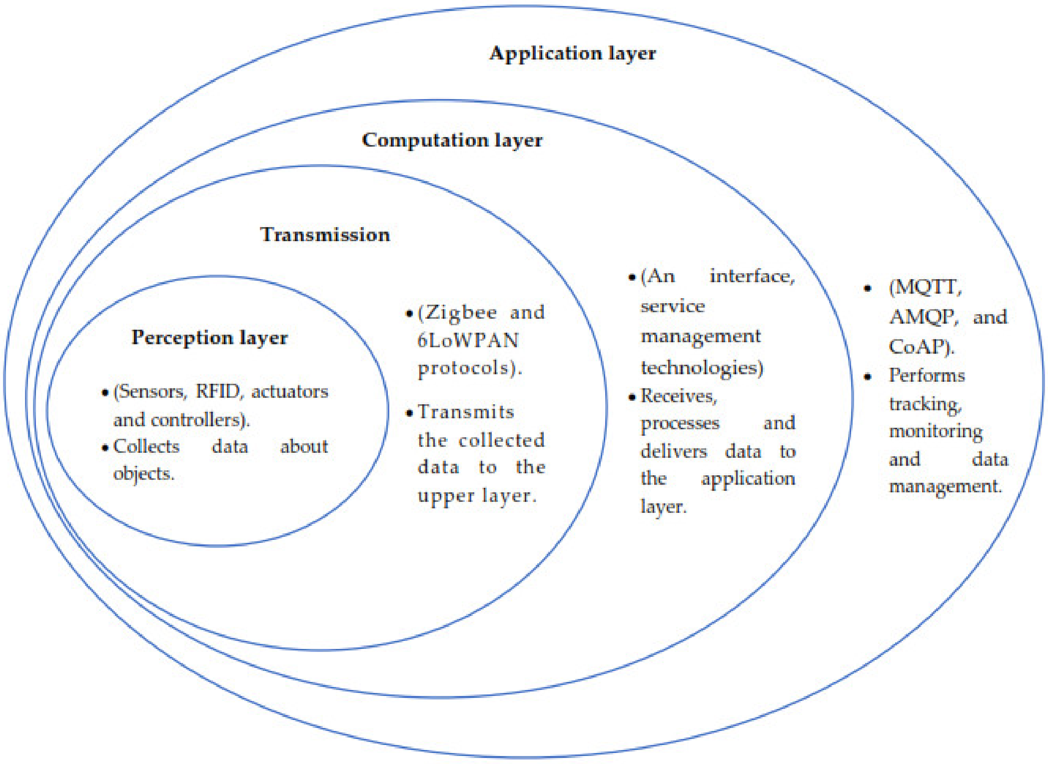

Figure 1. Architecture of IoT application.

4. Implementation of IoT in Warehousing

4.1. Conceptual Framework of IoT Implementation in a Warehouse

SCM has several functions such as purchasing, production, inventory, distribution, routing, location and marketing (Mostafa and Eltawil 2016). From the literature, IoT can have a significant role in improving various functions of SCM. Figure 2 summarizes some potential benefits of this implementation. In today's business world, warehouses have a significant role in meeting customers' expectations. They serve as key sources of competitiveness measured by who can deliver the products faster with better cost efficiency and flexibility. In that sense, managers need to have a good understanding of everything related to warehousing and how it affects the whole supply chain (Richards 2017). Trappey et al. (2017) explained that the improvement of warehouses can be measured by speed and accuracy of meeting demands, effective management and decreased non-value-added functions. Another concern is the information integration that consists of key functions for inventory status updates, product tracking and order management.

Warehouses can contain thousands of products, that is why it should be optimally utilized to ensure accurate and fast performance in all functions to meet customers' demands. Applying IoT to warehousing promises a significant impact as it can be used to monitor several processes in the warehouse in real-time and can eliminate manual interferences. It can make everything connected to each other and hence enable the analysis of the vast amount of data captured from these connections and turns them into insights to support decisions and improve the total performance.

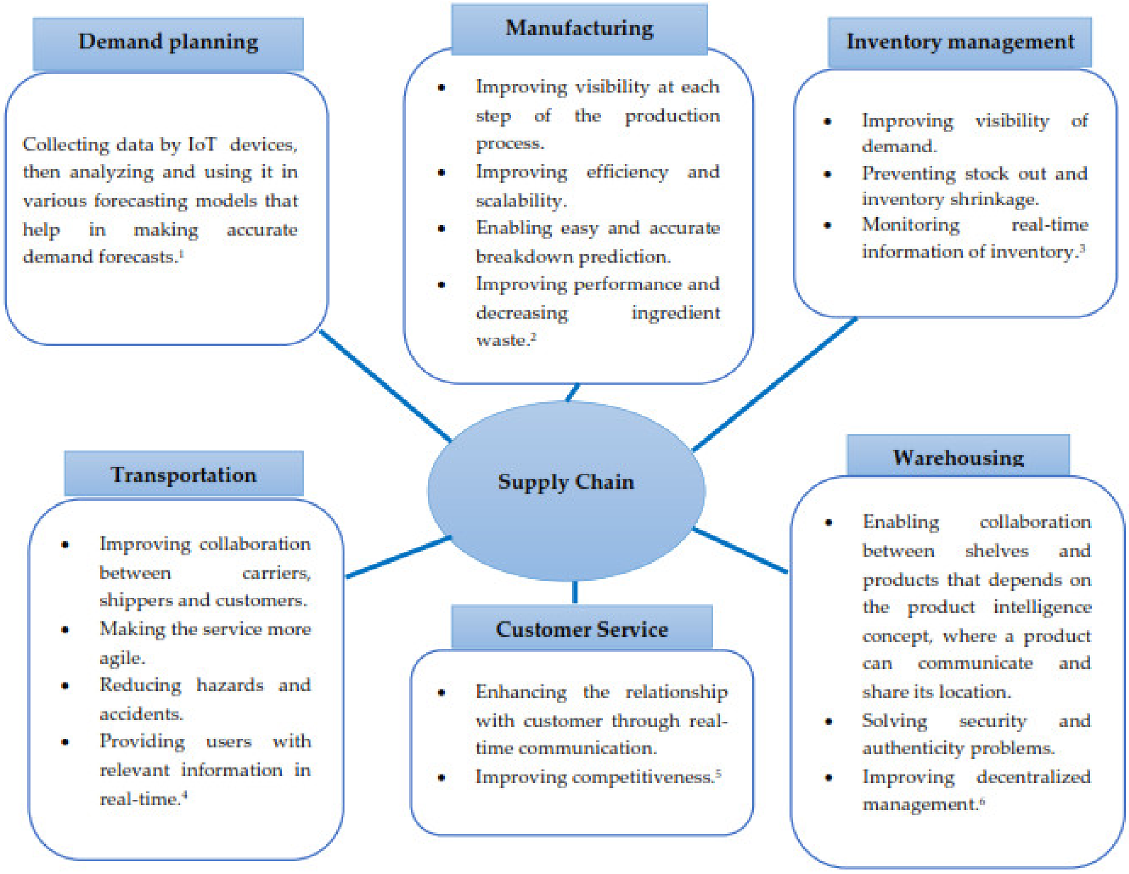

Figure 2. Benefits of using IoT in SCM functions (Yerpude and Singhal (2017), Anita and Abhinav (2017), Qin et al. (2017), Schoen et al. (2016), Ives et al. (2016) and Richards (2017).

In this work, a framework is proposed to implement IoT in warehousing operations. Figure 3 shows this framework. As soon as products pass through the in/out gateway, the reader attached on the gate captures data about products recorded on tags attached to them. This provides real-time visibility of inventory levels and prevents stock-outs. Readers attached to forklifts read data that includes the product's location, product type and expiry date, and share this data with the driver on an attached screen. Once the products are put on shelves, attached sensors give confirmation to the driver on the screen. Sensors are also used to monitor the Heating, Ventilation and Air Conditioning (HVAC) system in order to optimize energy consumption and assure product quality and warehouse safety. All the data captured from readers and sensors are transferred to the warehouse management system (WMS) that processes the data and converts it into useful information and actions. The same functions occur for order picking, when an order arrives, the driver goes to the location of the product that appears on the attached screen and makes a confirmation that it is the correct order via the readers attached to the forklift. As soon as the order leaves the warehouse, the inventory level is updated immediately. This makes order fulfilment more efficient, easier and accurate, and prevents counterfeiting.

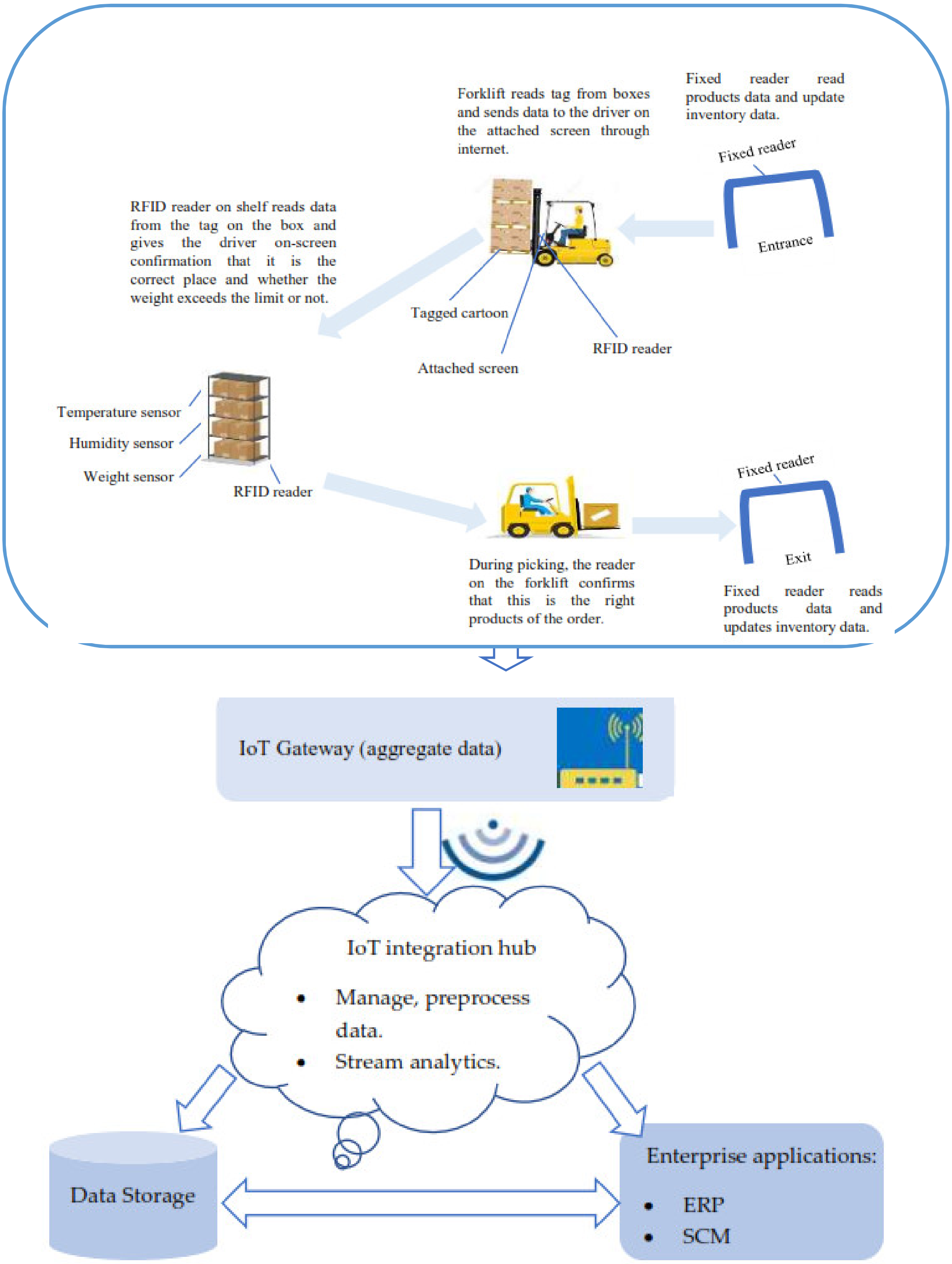

Figure 3. Proposed framework of implementing IoT in a warehouse.

4.2. Economic and Social Impact of the Proposed Framework

Reducing human intervention and making everything connected increase the efficiency and saves time, hence saves money. Implementing IoT in industry can lead to economic and social transformation; a 10% rise in the number of connected machines and objects can lead to an annual increase of 0.7% in GDP (gross dynamic product), 0.3% in services GVA (gross value added) and 0.9 in industry GVA (Rodríguez and Stammati 2018). Real-time data and information sharing through the cloud create massive values for companies and consumers, and help in making processes and services more efficient, reducing costs, improving quality, creating new sources of revenue, optimizing inventories, and improving equipment utilization (Szewczyk 2016). IoT also has a great impact on society; it offers great opportunities in everyday life and work. The massive amount of data generated can be used for developing more efficient systems as it reduces human intervention (BCS 2013). The proposed framework is expected to provide significant benefits for warehouses and supply chains through decreasing human intervention. Expected benefits include:

- Increasing efficiency.
- Ensuring safety of labor and goods.
- Reducing operational time.
- Reducing accidents.
- Minimizing the number of workers.
- Increasing reliability and accuracy of packing and picking processes.
- Decreasing counterfeiting, fraud and theft.
- Helping companies improve forecasts due to the availability of accurate data.
- Real-time data helps in accurate decision making.
- Enhancing the overall performance of companies.

All these benefits will improve the profit and the reputation of the organization. However, enterprises face multiple challenges in adopting IoT, with large number of devices connected and vast amounts of data generated, enterprises have to be concerned about security and privacy as the data could be hacked and stolen. Additionally, lack of technology standards can lead to negative consequences as manufacturers can design products that operate in any of the disruptive ways online. Adaption of IoT needs very high energy so energy demand is considered a big challenge of IoT, also waste disposal that adversely effects the environment and therefore, affecting the human lifespan.

5. Conclusions

IoT is a key technology of the fourth industrial revolution Industry 4.0. IoT is considered one of the most promising technologies to control and improve the performance of supply chains; warehouses are key parts of supply chain that contribute to the success of any industrial organization, so new technologies are gaining vast attention from a wide range of enterprises to improve performance, reputation and hence gain more customers and profit. In this paper, a review of Industry 4.0 technologies is provided (CPS, IoT and cloud computing), as well as information sharing in supply chains, and the previous research on implementing IoT in supply chains. Components of IoT infrastructure are categorized in four layers; the perception layer, the transmission layer, the computation layer and the application layer. In addition, the potential impacts of using IoT in different supply chain functions have been illustrated. Also, a framework of implementing IoT in warehousing operations was proposed with illustrating how it will bring more benefits to the warehouse and improve overall performance. Potential impacts on the economy and society have been illustrated. It was also discussed that the proposed framework can help in improving the performance of the warehouse, increase efficiency, prevent inventory shortage and counterfeiting, and make order delivering faster and easier, and hence increase the profit.

Future research should implement this framework on a real warehouse and compare the benefits expected from this proposal with the actual results; a simulation model can be developed to show the benefits of applying this framework.

Author Contributions: Conceptualization, N.M.; methodology, N.M. and W.H.; formal analysis, W.H.; writing—original draft preparation, W.H.; writing—review and editing, N.M.; supervision, H.E. and N.M.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

Anita, R., and Bodla Abhinav. 2017. Internet of Things (IoT)—Its Impact on Manufacturing Process. *International Journal of Engineering Technology Science and Research IJETSR* 4: 889–95.

Azab, Ahmed, Noha Mostafa, and Jaehyun Park. 2016. OnTimeCargo: A Smart Transportation System Development in Logistics Management by a Design Thinking Approach. Paper presented at 20th Pacific Asia Conference on Information Systems (PACIS 2016), Chiayi, Taiwan, June 27–July 1, p. 44.

Baihaqia, Imam, and Amrik S. Sohal. 2013. The impact of information sharing in supply chains on organizational performance: An empirical study. *Production Planning & Control: The Management of Operations* 24: 743–58.

BCS—The Chartered Institute for IT. 2013. The Societal Impact of the Internet of Things. Available online: https://www.bcs.org/upload/pdf/societal-impact-report-feb13.pdf (accessed on 27 January 2019).

Chopra, Sunil, and Peter Meindl. 2013. *Supply Chain Management: Strategy, Planning, and Operation*, 5th ed. London: Pearson Education.

Choy, King Lun, Angappa Gunasekaran, Hoi Yan Lam, Ka Ho Chow, Yick Chi Tsim, Tsz Wing Ng, Ying Kei Tse, and Xiao Ang Lu. 2014. Impact of information technology on the performance of logistics industry: The case of Hong Kong and Pearl Delta region. *Journal of the Operational Research Society* 65: 904–16.

Cortés, Beatriz, Andres Boza, David Pérez, and Llsnod Cuenca. 2015. Internet of Things Applications on Supply Chain Management. *International Journal of Computer, Electrical, Automation, Control and Information Engineering* 9: 2493–98.

Degryse, Christophe. 2016. Digitalisation of the Economy and its Impact on Labour Markets (10 February 2016). ETUI Research Paper—Working Paper 2016.02. Available online: https://ssrn.com/abstract=2730550 (accessed on 27 January 2019).

Dhumale, R. B., N. D. Thombare, and P. M. Bangare. 2017. Supply Chain Management using Internet of Things. *International Research Journal of Engineering and Technology (IRJET)* 4: 787–91.

Grabara, Janusz, Michal Kolcun, and Sebastian Kot. 2014. The role of information systems in transport logistics. *International Journal of Education and Research* 2: 1–8.

Hofmann, Erik, and Marco Rüsch. 2017. Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry* 89: 23–34.

Ibrahim, Sameh, Hatem A. Elayat, Mahassen M. Khater, and Noha A. Mostafa. 2011. Data analysis for inventory management in a multi-echelon supply chain. *International Journal of Economic Resources* 2: 138–50.

Imran, Muhammad, Waseem ul Hameed, and Adnan ul Haque. 2018. Influence of Industry 4.0 on the Production and Service Sectors in Pakistan: Evidence from Textile and Logistics Industries. *Social Sciences* 7: 246.

Ives, Blake, Biagio Palese, and Joaquin A. Rodriguez. 2016. Enhancing Customer Service through the Internet of Things and Digital Data Streams. *MIS Quarterly Executive* 15: 279–97.

Jia, Xiaolin, Quanyuan Feng, Taihua Fan, and Quanshui Lei. 2012. RFID Technology and Its Applications in Internet of Things (IOT). Paper presented at 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet), Yichang, China, April 21–23, pp. 1282–85.

Jonsson, Patrik, and Stig-Arne Mattsson. 2013. The value of sharing planning information in supply chains. *International Journal of Physical Distribution and Logistics Management* 43: 282–99.

Kovács, György, and Sebastian Kot. 2016. New Logistics and Production Trends as The Effect of Global Economy Changes. *Polish Journal of Management Studies* 14: 115–26.

Li, Bo, and Yulong Li. 2017. Internet of things drives supply chain innovation: A research framework. *International Journal of Organizational Innovation* 9: 71–92.

Lin, Jie, Wei Yu, Nan Zhang, Xinyu Yang, Hanlin Zhang, and Wei Zhao. 2017. A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications. *IEEE Internet of Things Journal* 4: 1125–42.

Manyika, James, Michael Chui, Peter Bisson, Jonathan Woetzel, Richard Dobbs, Jacques Bughin, and Dan Aharon. 2015. Unlocking the potential of the Internet of Things, McKinsey & Company. Available online: https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world (accessed on 12 January 2019).

Mostafa, Noha, and Amr Eltawil. 2016. Vertical Supply Chain Integrated Decisions: A Critical Review of Recent Literature and a Future Research Perspective. In *Supply Chain Management: Applications for Manufacturing and Service Industries*. Edited by Mamun Habib. Management Science—Theory and Applications Series. New York: Nova Science Publishers.

Ng, Irene, Kimberley Scharf, Ganna Pogrebna, and Roger Maull. 2015. Contextual variety, Internet-of-Things and the choice of tailoring over platform: Mass customisation strategy in supply chain management. *International Journal of Production Economics* 159: 76–87.

Qin, Wei, Ray Y. Zhong, Hongyon Dai, and Z L. Zhuang. 2017. An assessment model for RFID impacts on prevention and visibility of inventory inaccuracy presence. *Advanced Engineering Informatics* 34: 70–79.

Reaidy, Paul J., Angappa Gunasekaran, and Alain Spalanzani. 2015. Bottom-up approach based on Internet of Things for order fulfillment in a collaborative warehousing environment. *International Journal of Production Economics* 159: 29–40.

Richards, Gwynne. 2017. *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*, 3rd ed. London: Kogan Page Publishers.

Rodríguez, José María and Luigi Stammati. 2018. The Economic Impact of IoT putting numbers on a revolutionary technology. *Frontier Economics*. Available online: https://www.frontier-economics.com/media/1167/201803_the-economic-impact-of-iot_frontier.pdf (accessed on 25 December 2018).

Schoen, Quentin, Matthieu Lauras, Sébastien Truptil, Franck Fontanili, and Anne-Ghislaine Anquetil. 2016. *Towards a Hyperconnected Transportation Management System: Application to Blood Logistics, International Federation for Information Processing*. Cham: Springer International Publishing, pp. 3–12.

Swamy, Sowmya Nagasimha, Dipti Jadhav, and Nikita Kulkarni. 2017. Security Threats in the Application layer in IOT Applications. Paper presented at International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017), Palladam, India, February 10–11, pp. 477–80.

Szewczyk, Pawel. 2016. Impact of the Internet of Things on the Economy and Society. *Organizacja I Zarządzanie/Politechnika Śląska* 3: 461–70.

Tejesh, B. Sai Subrahmanya, and K. Sripath Roy. 2017. A low-cost warehouse inventory management system using internet of things and open source hardware. *International Journal of Control Theory and Applications* 10: 113–22.

Trappey, Amy J. C., Charles V. Trappey, Chin-Yuan Fan, Abby P. T. Hsu, Xuan Kai Li, and Ian J. Y. Lee. 2017. IoT patent roadmap for smart logistic service provision in the context of Industry 4.0. *Journal of the Chinese Institute of Engineers* 40: 593–602.

Vanpoucke, Evelyne, Ann Vereecke, and Steve Muylle. 2017. Leveraging the impact of supply chain integration through information technology. *International Journal of Operations & Production Management* 37: 510–30.

Wielki, Janusz. 2017. The Impact of The Internet of Things Concept Development on Changes in The Operations of Modern Enterprises. *Polish Journal of Management Studies* 15: 262–75.

Wollschlaeger, Martin, Thilo Sauter, and Juergen Jasperneite. 2017. The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0. *IEEE Industrial Electronics Magazine* 11: 17–27.

Yan, Bo, Chang Yan, Chenxu Ke, and Xingchao Tan. 2016. Information sharing in supply chain of agricultural products based on the Internet of Things. *Industrial Management & Data Systems* 116: 1397–416.

Yerpude, Samir, and Tarun Kumar Singhal. 2017. Impact of Internet of Things (IoT) Data on Demand Forecasting. *Indian Journal of Science and Technology* 10: 1–5.

Zhou, Keliang, Taigang Liu, and Lifeng Zhou. 2015. Industry 4.0: Towards future industrial opportunities and challenges. Paper presented at 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Zhangjiajie, China, August 15–17.