Towards a Smart Warehouse Management System

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Abstract.

In any supply chain, the warehouse is a main component in linking the chain partners and nowadays it acts as a competitive factor. Hence, it has become very necessary to manage warehouses effectively and allocate their resources efficiently. Warehouse Management Systems (WMSs) have been developed for monitoring, tracking and controlling the warehouse operations, but with the increasing dynamicity of the market, traditional systems have become less efficient and unsuitable for today's market requirements, that is why new technologies have started to emerge to be used for such applications. Internet of Things (IoT) is a promising technology that can be used in the context of Industry 4.0. In this paper, a smart WMS framework based on IoT is proposed; this system helps the warehouse manager to achieve more control and monitoring of the operations in real time. A review of WMS and IoT implementation in warehouses is presented. Also, the blocks and layers of IoT are illustrated. Finally, the benefits and challenges of implementing IoT in the supply chain and the warehouse are discussed.

Keywords

Internet of Things, Warehouse Management System, Supply chain

1. Introduction:

"The supply chain describes the process of delivering a product or service from start to finish" (Andreas and Simon, 2016). It aims to achieve co-ordination and linkage between all process across the supply chain such as; suppliers, customers and organization itself thus, improve the performance of the supply chain and reduce costs for example; it helps reducing buffers of inventory by sharing information related to demand and inventory levels.

Warehousing is a key function of supply chain management. Accorsi et al. (2014) defined the main function of warehousing is "to receive products (from inbound or manufacturing lines), to store materials until they are requested, and then, to extract products from inventory and ship them in response to the customers' orders". In the past, managing inventory focused on inspecting the processes to improve the performance of the warehouse. The inspection process did not need to use information technologies (IT) tools. In the last decade, warehouse operations have become more complex with an increasing number of items to be processed in a warehouse, so traditional and manual methods of warehouse management are no longer adequate or practical to manage this vast amount of operations, this led to an increased usage of IT in order to deal with these complexities. Since the 2000s, more complicated tools and algorithms started to appear to manage warehouses efficiently, which led to the evolving of Warehouse Management System (WMS) (Staudt et al., 2015). WMS is an information system that integrates software systems to monitor, control, manage quantities and storage locations and optimize warehousing decisions. The key functions of WMS are order processing, order release and master data, the extended functions are receiving (inbound), put-away and warehouse control. The most popular software in managing warehouses is Enterprise Resource Planning (ERP) system that offers tools for several functions of the enterprise such as: accounting, finance, control and production planning (Nettsträter et al., 2015). However, the market has become more dynamic and needs more flexible software for meeting market requirements and challenges. Hence, new approaches have been introduced to meet these challenges; one of these new technologies is the Internet of Things (IoT). Okano (2017) has defined IoT as "the ubiquitous and global network that helps and provides the functionality of integrating the physical world. This is done through the collection, processing and analysis of data generated by IOT sensors, which will be present in all things and will be integrated through the public communication network". The main concept of IoT is to make everything identified, sensed and connected to the internet and be capable to connect with each other. Massive amount of data is generated from these connections, and then this data is converted to information to support decision-making (Cortés et al., 2015). IoT is considered a key technological that is ushering towards industry 4.0 revolution, its infrastructure depends on many communication technologies such as Wi-Fi, Bluetooth, Radio Frequency Identifications (RFID), sensors, and cloud computing. It provides a new and efficient way for gathering and sharing information that help in managing supply chain efficiently and in converting it to a smart one; for example, IoT can be used in managing warehouses by tracking and monitoring products, demand forecasting, inventory management and getting real-time data about every process which can lead to preventing bullwhip effect that results from sharing incorrect information.

This paper is organized as follows: Section 2 gives a literature review about WMS and the previous research that integrates IoT in supply chains and warehousing. Section 3 illustrates IoT building blocks and architecture layers. Section 4 discusses the potential of implementing IoT in WMS, and a conceptual framework for this implementation, and the expected challenges. Finally, conclusions are given in section 5.

2. Literature Review

2.1 Warehouse Management System

Nee (2009) studied the impact of adopting WMS on the overall business performance through using wireless barcodes and Management Information Systems (MIS), it was found that adopting WMS helps in reducing costs, making management more efficient, making process more flexible, and making lead-time delivery shorter, thus meeting customer requirements faster, increasing customer satisfaction that improves competitiveness, and also helping in inventory investment reduction. Sahuri and Utomo (2016) presented a system based on web service that can help small enterprises to improve their warehouse management and business, the main idea of this system is to send information about the stock to the mobile phone through Short Message Service (SMS), it helps in supporting faster and easier decision-making because it provides accurate data compared to the manual system that depends on recording all items the manually. Adiono et al. (2017) proposed an RFID-based goods locator system that consists of RFID tags attached to the items including information about them, and RFID readers to sense the distance to the location of the purchased item. The reader is connected by Bluetooth to a WMS installed in a smartphone. This system helps in updating inventory in a real-time, shortening the time needed to find the purchased items, increasing the efficiency of the WMS and providing faster delivery. Oner et al. (2017) designed an RFID-based information system framework for a wool yarn industry for the purpose of tracking work-in-progress, counting and tracking inventories, picking, receiving and shipping of semi-finished products. The authors have also performed a cost-benefit analysis for the proposed system that reduced the required workforce by 20% and decreased the lost work-in-progress rate, thus reducing costs and improving the overall performance of the wool yarn industry. Wei et al. (2015) discussed the functional design of the WMS for a pharmaceutical enterprise by using barcode management application, it helped in managing inventories effectively, decreasing workforce costs, and supporting decision making depending on data warehouses. Qin et al. (2017) studied the impact of using RFID on the problem of inaccurate inventory through proposing an assessment model. The inaccurate inventory problem resulted from information distortion through the supply chain is called the bullwhip effect; this problem leads to an increase in holding and shortage costs. The authors founded that utilizing RFID in the downstream results in more benefits and efficiency compared to when utilizing it in the upstream stages.

Han and Zhu (2017) analyzed the logistics of warehousing system and analyzed the existing problems for the purpose of finding methods to improve logistics and storage system. The authors have presented an optimization design of logistics and warehousing by establishing a warehouse management information system that can improve the efficiency of the enterprise, strengthen the coordination between all departments, reduce labor size, solve the problem of material confusion and reduce costs. Patil et al. (2018) proposed a dynamic web application system by using a Software-as-a-Service (SaaS) that provides a cloud-based application of WMS, this helped in converting manual work to a software work that helps the user to access data easily and fast and make work more accurate, the proposed system also helped in managing warehouses effectively, increase visibility, capture real-time data and provide a graphical analysis for product stocks, purchase order, stock in and stock out. Woźniakowski et al. (2018) discussed the difference between ERP systems and WMSs, they founded that the two systems supplement each other, and their integration brings most profit to the enterprise. Pane et al. (2018) implemented an RFID system in WMS by using Arduino Uno microcontroller and found that it facilitated the work of warehouse labor, helped in controlling operations efficiently, speeded up work processes, reduced error rate, increased warehouse productivity and modernized work processes. Mao et al. (2018) designed a functional framework of intelligent WMS based on cloud model using RFID and GPS and proposed a hybrid genetic algorithm based on bee colony optimization to solve the scheduling problem of the cloud, the proposed system provided a real-time data that helped in making better scheduling and decision making.

Information sharing has played a vital role in managing supply chains efficiently, it contributes in reducing the bullwhip effect and improving the performance of the whole supply chain. Jonsson and Mattsson (2013) studied the impact and value of sharing four types of planning information on the inventory capital using re-order point methods by developing a simulation model, the types of information were stock-on-hand data, customer forecasts, planned orders and point-of-sales data, they found that the impact and value of shared information depends on whether the demand is stationary or not; in the case of stationary demand, the stock-on hand information has higher value, in the case of the non-stationary demand, the planned order and demand forecast information has high value. Shared information about point-of sales has no value whether demand is stationary or not, thus it is very significant to decide how and when to share planning information.

2.2 Using IoT in supply chains and warehousing

Since the evolution of IoT, researchers started to explore the possibility of using this technology in several fields. Few studies addressed this implementation in the field of Supply Chain Management (SCM). In the field of agricultural supply chains, Yan et al. (2016) proposed an IoT-based model that uses RFID for solving the problem of imperfect information and bullwhip effect and introduced two methods of information inquiry for static and dynamic information that help in increasing supply chain efficiency, improve the authenticity and quality of the products because they help operators to easily trace, track and inspect products anytime and in any stage.

Qu et al. (2016) proposed an IoT-based real-time production logistics synchronization system under cloud manufacturing environment that integrated cloud manufacturing and IoT infrastructure to face the dynamics occurring in production logistics processes. They considered the proposed system as an adaptive solution to plan infeasibility that results from execution dynamics, the proposed system provides a general method for mixing IoT and cloud manufacturing implementation. Ding (2013) presented a smart WMS based on IoT that provides a great amount of information about different goods by using sensors technologies, thus providing intelligent processing, more control on the storage compared to the traditional system, improved efficiency, reduced costs and reduced error rate. Lee et al. (2018) proposed an IoT-based WMS with advanced data analytical approach by using computational intelligence techniques integrated with the fuzzy logic technique to select the suitable method for picking process. This system could provide better warehouse performance, improved order fulfilment, enhanced packing method, better inventory tracking and improved overall performance of the warehouse. Tejesh and Roy (2017) developed an inventory management system based on open source hardware and IoT; it can be used for tracking, monitoring and collecting data about products; such as the stockroom and details of a specific product. Reaidy et al. (2015) proposed an IoT infrastructure based on RFID and a negotiation protocol for collaborative warehouse order fulfillment that exploit concepts of competition and cooperation between agents. They constructed an example of a collaborative warehouse to validate the proposed system and to find the impact on demand response while minimizing fuel and labor costs. For decentralized warehouse management, warehouse visibility, transparency and traceability can be improved by using this platform, thus the performance of the whole distribution processes can be improved.

Ng et al. (2015) developed a simple analytical framework to study the impact of using IoT in SCM, the authors also illustrated how to translate data collected by IoT to a meaningful information and inputs which help in managing the supply chain by choosing between two strategies; the first strategy is platform strategy that states that the suppliers have the ability to produce standardized but flexible products that can be modified according to customers' demand. The second is tailoring that states that it is necessary to produce multiple product varieties to meet customers' demand. By maximizing the customers' added value, these two strategies can be more profitable. Li and Li (2017) showed how IoT cloud can improve the SCM performance, especially Supply Chain Innovation (SCI) through a proposed framework. The authors illustrated how integration of data between resources, processes and activities can improve the performance of all the supply chain partners. Cortés et al. (2015) presented some applications of implementing IoT in supply chains such as implementing it in the agriculture field. They emphasized IoT role in reducing supply chain-related costs, managing product information and improving the supply chain efficiency. Jia et al. (2012) presented a definition of IoT and the challenges in implementing it, also discussed how it can be applied in different areas such as supply chain and logistics for many purposes such as; tracing, tracking, supervising and monitoring that leads to real-time management for the whole system and makes the supply chain more agile and flexible.

3. IoT building blocks and architecture layers

The concepts of IoT blocks and layers are still not well-defined, different perspectives were addressed through literature. In this section, those different perspectives are overviewed.

3.1 Building blocks of IoT

IoT architecture can be explained through the concept of building blocks, because its architecture varies depending on the application where it is adapted. Figure 1 gives an illustration of the four basic building blocks for implementing IoT: things, gateways, network infrastructure and cloud infrastructure.

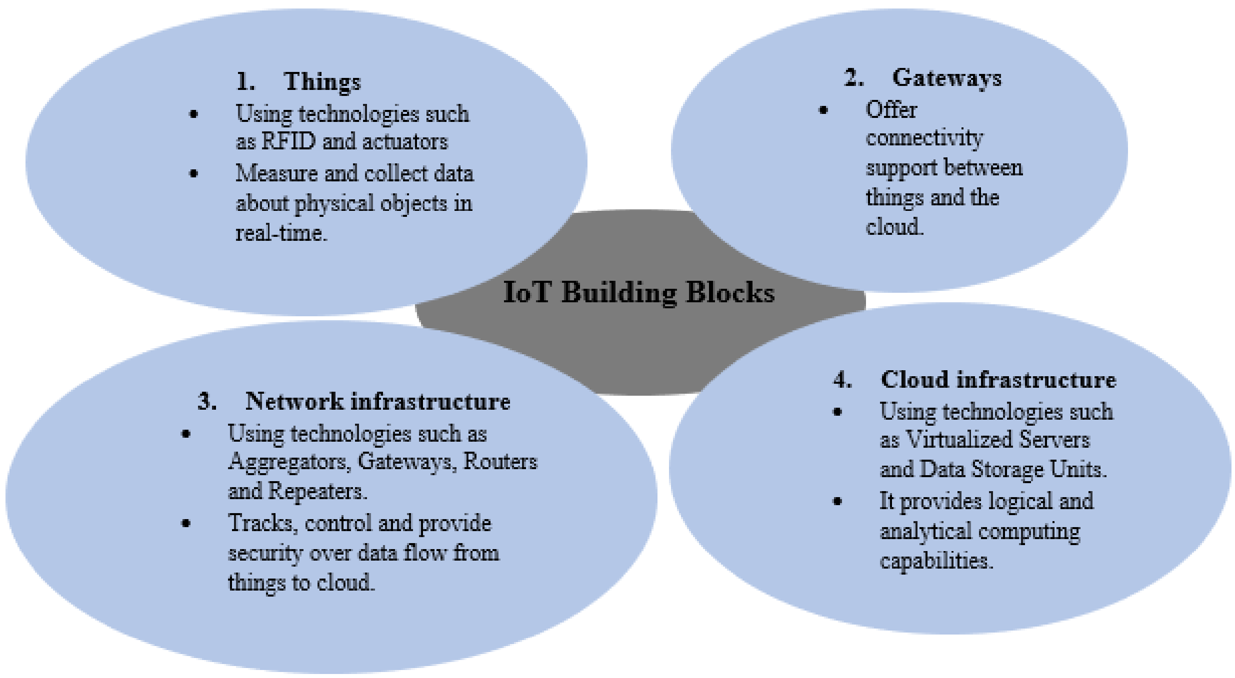

Figure 1. IoT building blocks

3.2 Architecture layers of IoT

Architecture layers vary depending on the application where IoT is used. Different architectures have been proposed by researchers. According to Pacheco and Hariri (2016), the architecture of IoT consists of four layers; the first layer is the devices layer that is responsible for capturing information from physical objects using technologies such as sensors that represent physical world in the digital world and actuators that adjust the environment to a desired state. The second layer is the network layer that is responsible for providing connectivity from/to nodes by using various technologies such as: internet, Wireless Sensor Networks (WSNs), network infrastructures, mobile communication networks and communication protocols. The third layer is the services layer which is considered as a link between application layer and network layer, all the computational power required is provided as a cloud to monitor and control data flow. The fourth layer is the application layer that provides interaction method for users according to their needs; from this layer users can access the IoT services by using technologies such as mobile applications.

According to Farahani et al. (2017) there are four basic layers for IoT infrastructure. Each layer has inherent security issues connected with it. The first layer is sensing layer, its main function is to identify, track and collect data from physical objects by using many technologies such as: WSNs and actuators that are used to monitor and track the status of objects, RFID tags that are used to identify and track objects, then the collected data is transmitted to the networking layer which acts as a link between cloud and physical objects and is responsible for transmitting data to service layer through wired and wireless network. Many protocols are used in this layer such as: Zigbee that is a wireless network technology which has the advantages of low energy consumption, low cost, low complexity and reliability, and Low-power Wireless Personal Area Networks (LoWPAN) that provide great connectivity with self-organization and low energy consumption. The third layer is the service layer that provides efficient and secure services to networking layer and interface layer by managing all types of services to satisfy user requirements. Analytics and service management are used for collecting, analyzing, exchanging, and storage of data and for decision making. The last layer is the interface layer that is responsible for delivering output to the user smoothly, provides interaction methods between users and other applications to get and analyze data.

According to Lin et al. (2017) and Mahmoud et al. (2015) IoT architecture consists of three layers; the first is the perception layer, its main objective is to connect things into IoT network, collect, measure and process data about these objects by using smart devices like RFID, sensors and actuators. The second layer is the network layer that is responsible for receiving information from the perception layer and transmitting it to the IoT hub. Different communication technologies are integrated in this layer such as; Wi-Fi, gateway, hub and switching, etc. the third layer is the application layer that receives data from the network layer to provide the required services, every application has different requirements in this layer like smart cities, smart logistics and smart transportation.

4 Integration of IoT with WMS

4.1 Benefits of implementing IoT in a supply chain

There are several functions of SCM such as inventory, routing, distribution, location, purchasing, production and marketing (Mostafa and Eltawil, 2016). Recent literature argued that IoT can have a significant role in improving various functions of SCM. IoT and connected devices help in managing transportation flows in the supply chain through informing the user with relevant information in real-time, this can establish a strong collaboration between carriers, shippers and customers, make service more flexible and agile and reduce hazards and disruptions (Schoen et al., 2016). The massive digital data streams generated by IoT devices help in improving customer services, it creates more opportunities for improving competitiveness because it enhances the relationship with the customer through real-time communications (Ives et al., 2016). For warehousing, IoT can make a warehouse more intelligent; it provides a strong collaboration between products and shelves to allow the product to communicate with its location. It also helps in supporting decentralized management and solving security and authenticity problems (Richards, 2017). Real-time data gathered from IoT system can be analyzed and used in various forecasting models that enables making more accurate demand forecast and responding proactively to market dynamics (Yerpude and Singhal, 2017). Implementing IoT in the manufacturing process offers several benefits to the enterprise; it improves the following features: visibility at each stage of the production process, efficiency and scalability, accurate breakdown prediction, ingredient waste reduction, and performance improvement (Anita and Abhinav, 2017). Smart devices can help also in managing inventory correctly by providing and monitoring real-time information of inventory, thus improving visibility of demand, preventing stock-out and inventory shrinkage (Qin et al., 2017).

4.2 Conceptual framework of IoT implementation in a warehouse

In today’s business world, warehouse is having a significant role in ensuring customer expectations. It serves as a key source of competitiveness measured by who can deliver the products faster with better cost efficiency and flexibility. In that sense, managers need to have a great understanding of everything related to warehousing and how it affects the whole supply chain (Richards, 2017). Trappy et al. (2017) have explained that the improvement of warehouses can be measured by the accuracy and speed of meeting demands, the decrease in non-value-added functions and effective management. Another concern is the information integration that consists of key functions for inventory status updates, order management and product tracking.

Because a warehouse can contain thousands of products, it should be optimally utilized to ensure fast and accurate performance in all functions for meeting customers’ demands. Applying IoT in warehousing promises a significant impact because it can be used to eliminate manual interferences and to monitor several processes in the warehouse in real-time. IoT makes the warehouse more intelligent; it can make everything connected and hence enabling the analysis of the vast amount of data captured from these connections and turn them into insights to support decisions and improve the whole performance.

In this work, a framework is proposed to implement IoT in warehousing operations. Figure 2 shows a flowchart for this framework. As soon as products with attached tags pass through in/out the gateway, the reader attached on the gate captures data from the tags, this prevent stock-out by providing real-time visibility of inventory levels. When products are loaded on the forklift, readers attached to it read data that includes product's type, product's location and expiry date, and share this data with the driver on an attached screen. Once the products are put on shelves, attached sensors give a confirmation to the driver on the screen. Sensors can also be used for monitoring Heating, Ventilation and Air Conditioning (HVAC) system to optimize energy consumption and to assure warehouse safety and products' quality. 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 make 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, also it prevents counterfeiting. All this captured data from readers and sensors is transmitted via internet to the WMS which process the data and convert it to useful information and actions.

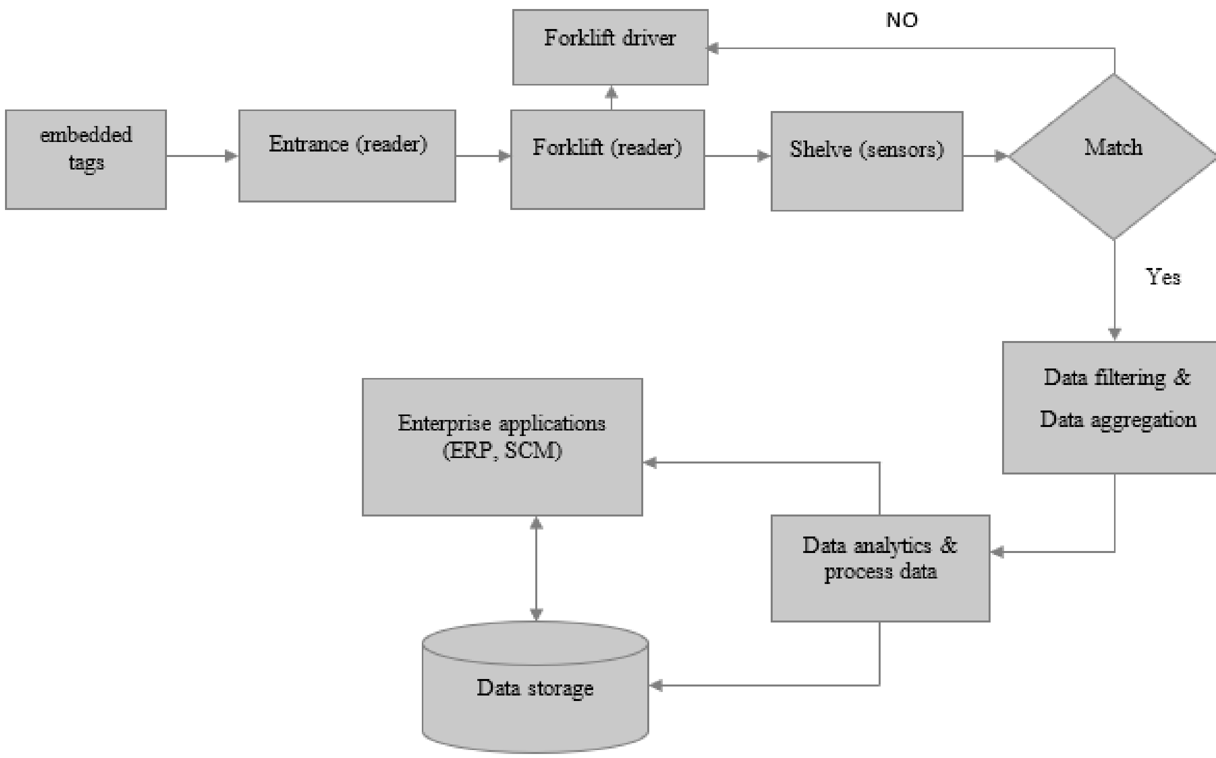

Figure 2. A flow char for implementing IoT in a warehouse

The proposed framework can be seen as a guideline for enterprises to improve the warehouse performance that has a significant effect on the performance of the whole supply chain. This framework can improve the performance of order fulfillment process because it provides the location of any product when required by helping the workers to find the assigned product faster. It can also improve the performance of the storage process because the data about the product is captured as soon as it arrives to the warehouse which reduces the time needed to check the products in. It also makes the orders more accurate because the sensors on the forklift give confirmation that the order is correct, thus improving the picking process. The proposed system also improves inventory accuracy because it does not depend on manual operations but depends on the readers attached to the entrance and the exit, which can significantly reduce mistakes, theft and counterfeit issues. However, based on the review on IoT, enterprises may face multiple challenges in adopting IoT; with large number of devices connected and vast amount of data generated enterprises have to give big concern to privacy, security and safety because the network can be potentially hacked.

5. Conclusion

IoT is a promising technology that can be used for building a smart WMS for monitoring and tracking items. This paper summarizes the basic building blocks of IoT and its layers and the potential impact of using it in the supply chain. The framework proposed illustrated how this technology can help in providing a 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 operations.

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