

Investigation of IoT applications in supply chain management with fuzzy hierarchical analysis

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ARTICLE INFO	ABSTRACT
<p>Received: 08 April 2022 Reviewed: 10 May 2022 Revised: 22 May 2022 Accepted: 28 May 2022</p>	<p>The IoT is currently growing rapidly and uses technologies such as smart barcode sensors, RFID, wireless communications, cloud computing, and more. The Internet of Things, in addition to being a revolutionary technology for all industries; has also demonstrated its potential in processes such as supply chain. Management, forecasting, and monitoring applications help managers improve the operational efficiency of their company distribution and increase transparency in their decisions. So more than ever, the benefits of using the Internet of Things are evident in the supply chain. The existence of comprehensive and valid information platforms is one of the requirements of supply chain management. Therefore, the most accurate use of integrated information devices such as Internet technology of objects in this part of the management of the organization is important. Coverage of this information accurately and in an instant facilitates matters and makes the process progress more transparent. To improve this process, cloud computing is used as a solution. In addition, other cloud computing capabilities can be used, such as facilitating object communication, integrating monitoring devices, and IoT storage, analyzing data, and paving the way for cyberspace to provide the customer with supply chain management. This requires a model that defines how Internet technology relates to objects, cloud computing, and supply chain management. The purpose of this study is to identify and prioritize IoT applications in the supply chain management sector with a multi-criteria decision-making approach. The results show that applications such as intelligent control and intelligent maintenance have the highest priorities.</p>
<p>Keywords: <i>IoT, Supply Chain Management, Multi-Criteria Decision Making, Fuzzy Prioritization.</i></p>	

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1. Introduction

With the rapid advancement of the Internet as well as intelligent technologies such as RFIDs and sensors, the Internet of Things has bypassed the early stages and is thus the IT technology revolution that transforms the Internet from a static environment to a dynamic and integrated environment. The Internet of Things has made it possible to connect smart devices and manage systems; In a way that facilitates the process of affairs with little human intervention or without any intervention (Nahr et al., 2021). The Internet of Things has affected our world from health monitoring, intelligent services and integrated logistics to standalone drones. The Internet of Things can optimize supply chain management, use resources efficiently, make the entire supply chain visible so that it can improve supply chain information transparency, manage supply chain in real time, and finally, agility. Brought top and complete integration for the supply chain (nozari et al., 2021). Various advances in IT capabilities have changed the face of the industry more rapidly than in the past decade. The adoption and implementation of information technology is one of the methods that applies a distinct competitive personality to companies and the supply chain. Adoption of information technology and its efficient implementation can improve cooperation between supply chain members through the rapid transfer and distribution of accurate information and the use of information systems and increase the efficiency of the supply chain (Szmelter-Jarosz et al., 2021).

Studies show the impact of information technology on improving responsiveness, distribution and transmission of information, chain efficiency and enhancing cooperation in both internal and external dimensions, preventing the effect of leather whipping and developing sales channels. Applications of information technology in supply chain management with two approaches of technology and information systems are also very important. Studies have shown that factors such as the size of the organization, success rate, uncertainty, and pressure from other chain partners play an important role in the adoption of information technology (Ghahremani-Nahr et al., 2022). Devices and tools include sensors and actuators. They have limited capabilities in computing, data storage, and transmission, and perform tasks such as monitoring environmental conditions, gathering information, and changing system parameters. The communications and network layer provides data communications and network infrastructure for the transmission of device data. The data center allows access to and storage of information. This layer can be hardware and a platform in local data centers or services in the cloud (Mohammadi et al., 2015). The logistics industry plays a very important role in the supply chain. Almost all goods depend on the transportation industry before production (raw materials) and after production. This dependence makes logistics a key issue in the supply chain for industry stakeholders. Today, with the decrease in the price of various sensors, we are witnessing the presence of the Internet of Things in all areas of logistics (Nozari et al., 2016).

Compared to the traditional supply chain, the IoT-based supply chain uses an information-sharing mechanism. Product information on the supply chain is sent to the management database through information readers in different parts of the network, and this database sends the necessary feedback through information analysis. This allows both price repairs and corrections to be done in a timely and correct manner. The information-sharing mechanism can enable manufacturers, distributors, and retailers to respond to market supply and demand information in a timely manner, and ultimately balance supply and demand and prevent product price fluctuations (nozari et al., 2021).

The use of the Internet of Things in the product supply chain not only improves the level of supply chain information but also reduces the risk of product security problems, especially food products, by controlling the supply chain. Also, when a product security issue occurs, companies can help resolve

the issue through the Internet of Things. Consumers can also access product information and reduce their purchase costs through electronic product labels. This article focuses on IoT applications in supply chain management and IoT utilization in businesses (Aliahmadi et al., 2022). Due to the increasing growth of this technology, in priority applications can increase the amount of IoT functions in different parts of the supply chain. Due to budget constraints and available resources, companies and supply chains cannot implement all of these applications in their business. Therefore, it is examined which of these applications has a higher priority for implementation in the supply chain? This helps supply chain managers make better and more accurate decisions about using the Internet of Things in the supply chain (nozari et al., 2022).

The structure of this article is as follows: The second part examines the research background. In the third section, the research method is described. The research findings are described in the fourth section and this method is used to prioritize these applications. The last section also summarizes and concludes.

2. Literature Review

The Internet of Things allows people and objects to be ideally connected at any time, any place, anything, any person, any path or any service used. Areas of IoT application are mainly based on industry, environment, and society, which are the supply chain management of transportation and logistics, aerospace and aviation are the industrial applications of IoT. There are several IoT devices in the supply chain. Devices such as autonomous and self-propelled vehicles, alarm sensors and customer information. But the most practical use of the IoT is to embed smart sensors in a product package to allow customers to track their goods across the supply chain until final delivery (Tavakkoli-Moghaddam et al., 2021).

Many of the early developments in the IoT and network infrastructure have focused on business procurement and product lifecycle; It enables everyone to access important information about products and places. Integration and collaboration with core business software operating systems can enhance business intelligence and standalone services through real-time analytics, turning the Internet of Things into a revenue-generating infrastructure. This enriches the information trade and accelerates business innovation (Guo et al., 2022). Focusing on business processes using IoT technology increases scalability and performance, leading to better decision making and new revenue streams through product management. IoT technology has played a vital role in operations excellence in supply chain management. This technology has significantly contributed to industrial automation, allowing the integration of industrial sensor networks, radio frequency-based detection networks, factory control networks, and information management systems. The Internet of Things can affect the entire supply chain. In this way, IoT can optimize supply chain management, use resources effectively, make the entire supply chain visible to improve the transparency of supply chain information. The IoT can manage the supply chain in real time, and ultimately make the supply chain fully agile and integrated. The Internet of Things affects supply chain management in the manufacturing sector, warehousing, transportation and sales (Kazancoglu et al., 2022).

In the manufacturing sector, by using the Internet of Things, production line automation can identify and track materials and products, thereby drastically reducing manpower costs, facilitating production industries, and improving product quality. By using the Internet of Things in the warehouse, the space can be optimized. By placing a label on the goods, the goods information can be transferred to the database, thus controlling the inventory and location of the goods. Intelligent sorting of goods and rapid and accurate review of inventory storage level are other applications of the Internet of Things in this area (Wójcicki et al., 2022). The ability to track products, increase company efficiency, facilitate agent

management, verify the halal status of goods, and monitor halal certificates are some of the things that are needed in the supply chain of halal products and the introduction of these products to the market. The Internet of Things helps to manage some of these. There are several challenges in this regard; these include the technical limitations of packaging machines, the immaturity of technology, the rejection of the user, and the legal and regulatory barriers that the IoT facilitates the understanding and analysis of the situation through the production of transparent data (Hrouga et al., 2022).

Based on the mentioned studies, it is observed that IoT can provide various services to supply chains and businesses. Taking advantage of these Internet of Things opportunities in businesses requires a thorough identification of its applications in the supply chain. Also, because supply chains are limited by resources, including monetary and financial resources, knowledgeable manpower, etc., it is necessary to prioritize these applications. To prioritize applications, we need criteria by which we can distinguish between applications. The main gap in current research is the lack of an approach to identifying IoT priorities in supply chain management, which is addressed in this paper.

3. The most important applications of IoT in supply chain management

Tracking and monitoring is one of the main goals of IoT deployment in supply chain management. This technology allows warehouse and fleet managers to track their shipments and inventory. However, the IoT has more potential for the supply chain. The IoT provides managers with a coherent flow of real-time data about product position and shipping environment. In this way, you will be warned if the goods are transported in the wrong direction and you can monitor the delivery of finished goods and raw materials. Thanks to environmental sensors, managers can track transport conditions and actively respond to changes. For example, one of the most common IoT solutions in the supply chain is displaying information about car temperature, pressure, humidity and other factors that can compromise product integrity. These conditions can also be adjusted automatically. Managers use IoT devices and data analysis systems to improve decision quality and increase the accuracy of delivery forecasts. Thanks to real-time tracking, companies are able to monitor goods during shipment and forecast delivery, as well as predict and reduce risks associated with delays. Figure 1 shows an example of a supply chain view using IoT technology. (Yu et al., 2022)

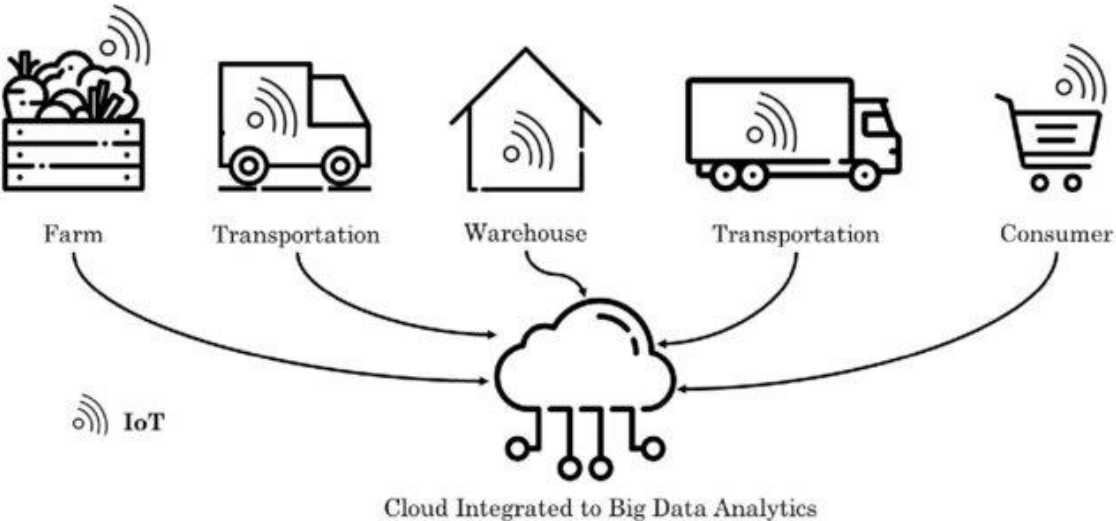


Fig. 1. Supply chain availability with the use of IoT devices (Correa et al., 2020).

The following describes the applications of the Internet of Things in the field of supply chain management, which are identified by reviewing various scientific and research articles and receiving feedback from experts, and our decision-making options (Desingh, 2022).

- ***Asset Management (W1)***

IoT systems facilitate asset monitoring and management. Instead of manually recording data or using older devices, managers can now rely entirely on software to update the status of all assets. Similar to retail asset tracking, connected technologies such as sensors, RFID tags and smart materials allow trouble-free tracking of each item and help supply chain managers gain instant access to key information about each delivery, including content. Gain package and storage.

- ***Automation (W2)***

There are many IoT applications in supply chain management that help automate warehouse operations, warehouse status monitoring, and remote control. Supply chain automation helps warehouse managers increase productivity, reduce costs, and increase flexibility.

- ***Improve resource management (W3)***

Connected systems collect the data needed for forecast analysis at various stages of the supply chain (equipment failure detection, maintenance forecasting, etc.). The power of IoT analysis and forecasting is widely used to improve resource management in many industries. With just the ability to predict system failure, supply chain and warehouse managers can significantly reduce downtime, thus saving a lot of money (Pal, 2022).

- ***Environmental Protection (W4)***

In an intelligent supply chain, the IoT is one of the technologies that helps managers comply with current environmental laws and publishing restrictions. Using various IoT sensors for supply chain management and asset tracking, they can now get an accurate picture of how resources are being used, such as electricity and water, and implement green strategies and environmental initiatives.

- ***Real-time tracking of shipments (W5)***

The IoT provides managers with a coherent flow of real-time data about product position and shipping environments. In this way, you will be warned if the goods are transported in the wrong direction and you can monitor the delivery of finished goods and raw materials (nozari et al., 2021).

- ***Monitor the storage status of the product at the time of shipment (W6)***

With the help of environmental sensors, managers can track transportation conditions and actively respond to changes. For example, one of the most common IoT solutions in the supply chain is displaying information about car temperature, pressure, humidity and other factors that can compromise product integrity. These conditions can also be adjusted automatically.

4. Research Methods

In this research, a fuzzy nonlinear hierarchical analysis method is used, which is represented by Mikhailov method. In this method, fuzzy even comparisons are assumed to be triangular fuzzy numbers. The definite weight vector (priority) $w = (w_1, w_2, \dots, w_n)$ is extracted in such a way that the priority rate is approximately within the range of the initial fuzzy judgments. In other words, the weights are determined so that relation (1) is established.

$$l_{ij} \leq \frac{w_i}{w_j} \leq u_{ij} \quad (1)$$

Each definite weight vector (w) holds with a degree in the above fuzzy inequalities which can be measured by the linear membership function of Equation (2) (in terms of unknown rate):

$$\mu_{ij} \left(\frac{w_i}{w_j} \right) = \begin{cases} \frac{(w_i / w_j) - l_{ij}}{m_{ij} - l_{ij}} & \frac{w_i}{w_j} \leq m_{ij} \\ \frac{u_{ij} - (w_i / w_j)}{u_{ij} - m_{ij}} & \frac{w_i}{w_j} \leq m_{ij} \end{cases} \quad (2)$$

Given the specific form of membership functions, the fuzzy prioritization problem becomes a nonlinear optimization problem in the form of Equation (3).

max λ

Subject to :

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq 0$$

$$(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \leq 0 \quad (3)$$

$$i = 1, 2, \dots, n-1, \quad j = 2, 3, \dots, n, \quad j > i,$$

$$\sum_{k=1}^n w_k = 1 \quad w_k > 0, \quad k = 1, 2, \dots, n$$

5. Research findings

The stages of evaluation and ranking are divided into two main parts, namely determining the matrix of pairwise comparisons and using mathematical modeling for ranking. This pairwise comparison table is shown in Tables (1). These tables are used for calculations by the Mikhailov method.

Table 1. Pair comparison matrix for IoT applications in supply chain management

	W1			W2			W3			W4			W5		
W1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W2	2.1	3.2	5.1	-	-	-	-	-	-	-	-	-	-	-	-
W3	2.1	2.8	4.7	2.3	3.1	5.2	-	-	-	-	-	-	-	-	-
W4	2.2	3.5	5.4	3.1	3.5	5.5	2.1	2.45	4.21	-	-	-	-	-	-
W5	1.2	2.5	3.25	2.1	2.35	4.1	3.1	3.5	4.2	1.7	2.5	3.25	-	-	-
W6	1.5	2.5	3.5	2.4	4.1	5.2	1.25	1.75	2.5	2.4	2.75	3.25	1.1	2.5	3.75

By placing the data from Tables 1 in the nonlinear model (3) and solving the model using LINGO software, the weight and rank of each application can be obtained. This is shown in Table (2).

Table 2. Weight and ranking of IoT applications in supply chain management

Application	Code	Weight	Rank	λ
Asset Management	W1	0.21124	2	0.3372
Automation	W2	0.11742	5	
Improve resource management	W3	0.10415	6	
Environmental Protection	W4	0.15142	4	
Real-time tracking of shipments	W5	0.25452	1	
Monitor the storage status of the product at the time of shipment	W6	0.16017	3	

6. Conclusion

This study, which aims to help artisans make IoT decisions, could guide IoT industrial investment. The numerous and costly applications of the Internet of Things in supply chain management, along with the constraints of financial resources, knowledge and manpower in companies, make us need a way to identify the most important priorities in this field for implementation in industry. The results of this research can be a beacon for managers and business owners. These results can be used in many supply chains to improve their efficiency and effectiveness. The results show that applications related to timely distribution, especially in the distribution networks of consumer products, which are also related to their health, are more important than other applications. This is because first-class applications simultaneously both facilitate sales and timely scheduling, as well as increase sales and profitability. According to the results, Real-time tracking of shipments has the highest priority among IoT applications in supply chain management. Other researchers can use new methods to evaluate the value that each of these applications adds to society (people and companies), and with futurist-based approaches to predict the value of each of these. Researchers and researchers can also examine the supply chains of each industry and identify and prioritize IoT applications in them, given the differences in supply chains in different industries. Also, the use of IoT in the supply chain has many technical issues such as related architecture, data storage, processing of collected data, etc., which can be the subject of some future research.

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