

The Use of the Internet of Things in the Cold Chain Logistics for a Better Vaccine Transportation: A State of the Art

Kenza Izikki^{1,*}, Jamila El Alami² and Mustapha Hlyal³

¹ LASTIMI Laboratory, University Med V in Rabat/ CELOG, ESITH, Casablanca, Morocco

² LASTIMI Laboratory, University Med V in Rabat, Morocco,

³ Center of Excellence in Logistics (CELOG), ESITH, Casablanca, Morocco.

*Corresponding Author

Abstract

Supply chains has become more complex and customer requirements keep on getting more demanding in terms of quality, time and sustainability. In respect to these transformations, the supply chain management strive to come up with new practices and approaches to mitigate these challenges and optimize the supply chain performance. In the pursuit of greater efficiency and competitiveness, Industry 4.0 has proved substantial strategic impact on global development. The enabling technologies of industry 4.0 mainly include the Cyber Physical System (CPS), Internet of Things (IoT), cloud computing, Blockchain etc. With its capability of sensing and generating valuable data throughout the value chain, IoT has attracted the interest of a growing body of researchers and practitioners. The “cold chain” logistics is a particular category of supply chains. It stands out from other types of supply chains by its demanding requirements and regulations which involves mainly perishable and temperature exigent products. While the technological advancements have contributed in the improvement of the cold chain, the logistical and transportation operations remains a main issue. In this perspective, this paper aims to explore the state of the art on the use of IoT in the cold chain logistics and in particular in the healthcare and vaccines supply chains. It discusses the challenges faced by the healthcare and vaccine cold chain logistics and points out the main benefit of IoT technologies.

Keywords: Healthcare and vaccines supply chain, Industry 4.0, IoT, Tracking, Visibility

1. Introduction

The industrial and business world is continuously undergoing tremendous changes and facing new challenges. Supply chains has become more complex and customer requirements keep on getting more demanding in terms of quality, time and sustainability. In respect to these transformations, the supply chain management strive to come up with new practices and approaches to mitigate these challenges, improve and optimize the supply chain performance.

We are living in an automated digital era where objects, machines and humans are all connected. This was established by the emergence of the forth industrial revolution; Industry 4.0. This revolution, powered by the recent advancements in the information and

communications technologies (ICT), works towards the integration of the virtual world and the physical world (Mastos et al., 2020). The enabling technologies of industry 4.0 mainly include the Cyber Physical System (CPS), Internet of Things (IoT), cloud computing, Blockchain etc. In the pursuit of greater efficiency and competitiveness, Industry 4.0 has proved substantial strategic impact on global development. More companies have witnessed the outstanding benefits of the industry 4.0 technologies adoption in reaching leading competitive advantage (Xu et al., 2018). With its capability of sensing and generating valuable data throughout the value chain, the internet of things has attracted the interest of a growing body of researchers and practitioners. (Abdel-Basset et al., 2018; Ben-Daya et al., 2019; ROCHA et al., 2017) and many more have focused on the correlation and relation between the internet of things technologies and the supply chain management. One of the main benefits of IoT in the supply chain management is its capability of tracking and generating real-time data across the complex supply chain, and thus monitoring the logistics operations (Mastos et al., 2020)

The “cold chain” logistics is a particular category of supply chains. It stands out from other types of supply chains by its demanding requirements and regulations which involves mainly perishable and temperature exigent products (Dong et al., 2021). The cold chains can be defined as “the equipment, processes and information management used to protect chilled and frozen [cargo, in which] the transport phases (i.e. loading, unloading, handling, and storage) play a fundamental role” (Castelein et al., 2020). This special chain aims to maintain the value and quality of the perishable goods and prevent any wastage and spoilage during their transport (Dong et al., 2021). The perishable products that employ the cold chains logistics are mainly fresh foods e.g. Fish meat dairy etc. and pharmaceuticals and vaccines.

The outbreak of the corona virus has disrupted every aspect of the human’s life. The conception of a vaccine was a worldwide priority. After securing the manufacturing of the covid-19 vaccine, the main challenge remains transporting and distributing the vaccines securely and wastage free.

While the technological advancements have contributed in the improvement of the cold chain, the logistical and transportation operations remains a main issue (Castelein et al., 2020). Consequently, the covid-19 vaccine logistics faces many challenges especially in the developing countries.

In this perspective, this paper aims to explore the state of the art on the use of the internet of things technology in the cold chain logistics and in particular in the healthcare and vaccines supply chains.

2. Material and Methods

This study aims to investigate the research developments on the use of the internet of things in the cold chain logistics and in particular the vaccine logistics. For this purpose, we have chosen to conduct a thorough literature review.

Literature review is a broadly used research methodology that help set a foundation for the research body as well as the practitioners. It is a way to summarise and synthesise the existing body of literature in a chosen area, providing a valuable overview and data that could be used as the groundwork for new frameworks and models conception (Snyder, 2019).

The conduction of the literature review has followed a systemic set of steps in order to ensure the transparency and quality of the findings. The first step was the establishment of the search strings that will be used for our review. These search strings are a combination of predefined keywords that are related to the area of study. These search strings associate the internet of things with the cold chain management in the healthcare field.

- “Internet of Things” and “vaccine transportation”
- “Internet of Things” and "cold chain management”:
- “Internet of Things” and “cold chain management” and vaccine logistics
- “Internet of Things” and “cold chain management” and healthcare
- "Internet of Things" and "Covid 19" and vaccine supply chain
- "Internet of Things" and "Covid 19" and cold chain
- "Internet of Medical Things" and "Covid 19" and "supply chain management"
- “Internet of Medical Things and Covid 19 and vaccine transportation
- "Internet of Medical Things" and "Covid 19"

A set of search engines were included in the primary study collection, namely Emerald Insight, Science Direct and google scholar.

In order to ensure the transparency of the study selection, a list of inclusion and exclusion criteria was developed. This list describes the data and relevancy that should be taken into consideration in the selection process. The publications should be in English and should be relevant to both IoT and the cold chain logistics in healthcare and vaccine transportation, any area that is not related to healthcare, and vaccines in particular will be excluded such as the use of cold chains for the food supply chains.

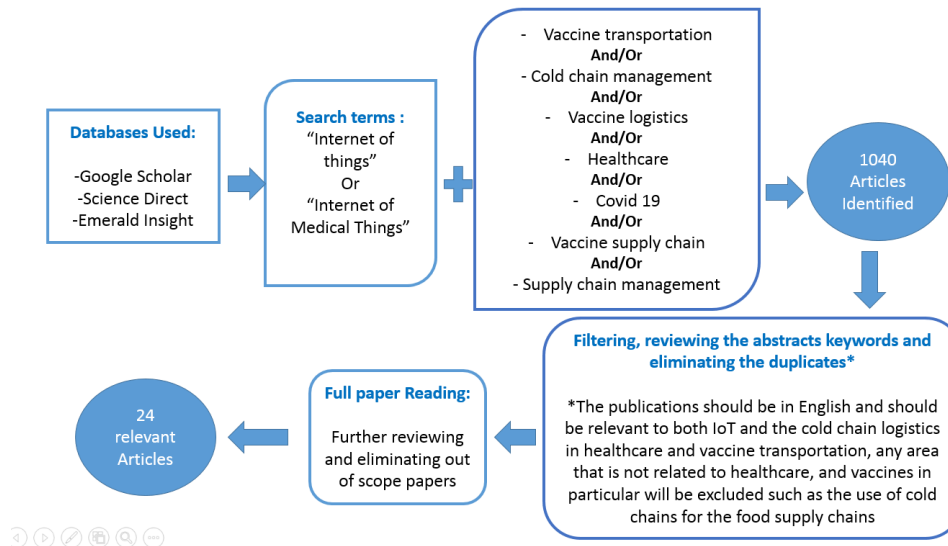
Different combination of the search words were used to find the largest amount of results related to our scope of research. However, the results were still limited and in particular, the papers related to our scope were very rare. 24 papers were selected from 1040 papers identified; that is only 2% of the identified papers were related to the use of IoT in the Vaccine supply chain.

Fig. 1 summarises the research method and identifies the number of papers found and selected, as well as the filtering criteria used.

3. Results and discussion

After a thorough material selection, a total of only 24 papers were identified as relevant to our scope of research. This section presents a descriptive analysis of the selected primary studies in terms of year of publication, type of paper and research methodology. It then discusses the challenges faced by the healthcare and vaccine cold chain logistics and summarises main benefit of IoT technologies and which IoT technologies were used in the selected papers.

Figure 1: Research method summary



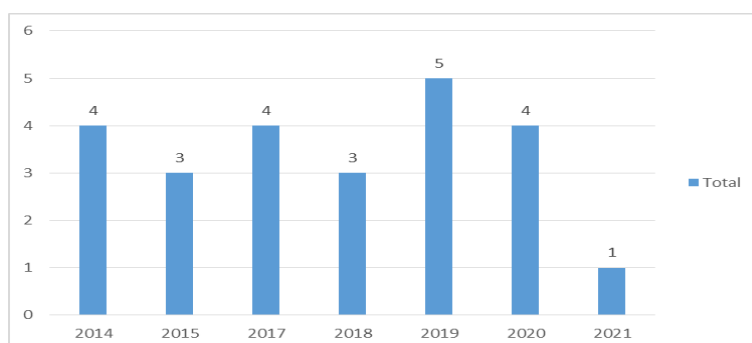
3.1 Descriptive analysis

3.1.1 Yearly-wise description

The earliest identified paper was in 2014, The figure shows a constant and regular paper production of papers in the scope of study. Albeit the pandemic crisis, academicians and researchers were more concerned on the conception of a vaccine and the control over the spreading of the virus.

The research concluded on 1st of March 2021. Therefore, the review search covers papers published until 1st march 2021. 2021 is currently the year where the vaccination is taking place, research on the use of technologies for vaccine transportation could increase during this year.

Figure 2: Yearly wise description



3.1.2 Publication type and research methodology

Fig.3 presents the distribution of the selected papers by publication type. The majority of selected papers (58%) were published in a journal. While the remains, were published in conference proceedings (33%) and books.

Figure 3: Publication type

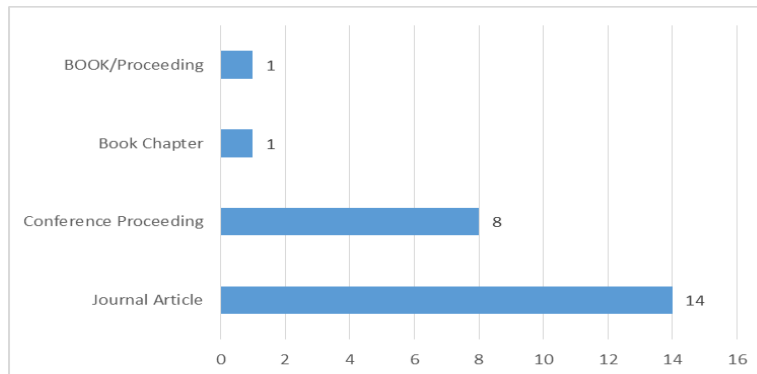
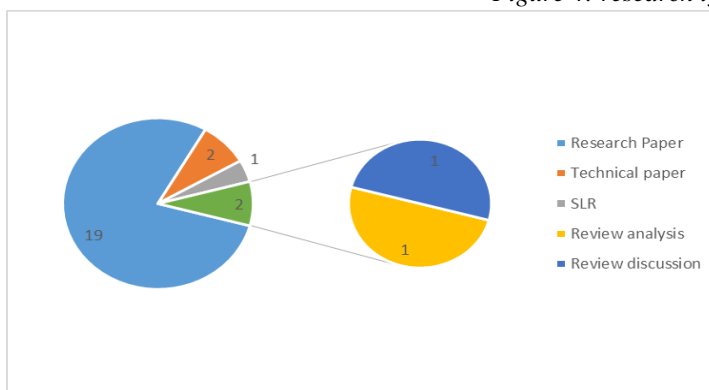


Fig4. shows the distribution of selected papers based on their research type. The majority of articles (79%) were research papers, while the rest were reviews or technical papers. 87% of papers are of conceptual nature; proposing new IoT systems and frameworks in the healthcare supply chain. The remaining of the papers are reviews and empirical survey/case studies, investigating the application of IoT in the healthcare industry.

Figure 4: research type



3.2 Cold Chain Logistics Challenges

The cold chain represents a unique type of supply chain due its demanding conditions for transportation (temperature, humidity, sunlight etc.) and critical expiry dates.(Tao et al., 2019)

Numerous challenges surround the efficiency and performance of the cold chain supply chain. The main challenge that cold chain logistics faces is how to manage the critical temperature-sensitive and perishable products. Many researchers have shed light on the importance of a safe transportation for sensitive products such as medications and vaccines(Bengiovanni et al., 2020), in order to avoid wastage and additional costs and expenses.(Daniela Antal et al., 2015)

Damaged products and un-usable pharmaceutical items remain the main concern for stakeholders(Marinelli et al., 2021). Efficient and optimised delivery is crucial for the safety of pharmaceutical products. Delays in pick-up and delivery lead to damaged products and

thus affect the cost and service satisfaction. These delays are mainly due to inefficient information flow. the lack of timely and accurate information throughout the logistics chain and inconsistent information transfer are the main challenge that cold chain logistics faces.(Marinelli et al., 2021; Usak et al., 2019) . Researchers and professionals have agreed on the crucial role tracking and monitoring plays in the performance of cold chain logistics.

In sum, monitoring and real time data management are the main challenges that cold chain supply chain needs to overcome in order to optimise its performance. In terms of cost, quality and customer satisfaction.

3.3 Cold Chain monitoring and Real-time decision making

Following the latter mentioned challenges, cold chain logistics' partners promptly need to overcome the critical hurdles in pursuance of a better cold chain and vaccine transportation.

The literature presents several solutions to optimise CCL, utilising different Internet of things technologies as well as combining them with various Industry 4.0 technologies such as Cloud Computing Artificial intelligence and Blockchain.

Table presents a summary of the literature findings, demonstrating the paper's main idea, as well as the main benefits of IoT in cold chain and vaccine transportation

Table 1: Summary of the literature

<i>Cod e</i>	<i>Main Idea of the paper</i>	<i>Main IoT Benefits</i>
1	<ul style="list-style-type: none"> • <i>Design of a wireless monitoring system based on LoRa technology</i> • <i>Application of the proposed system in the vaccine cold chain transportation system of the State Pharmaceutical Group.</i> • <i>The wireless monitoring system ensures quality quantity and safety of the products.</i> • <i>Temperature and humidity monitoring problem in the vaccine transportation can be completely solved after a year of use.</i> 	<ul style="list-style-type: none"> • <i>Monitoring of the vaccine cold chain</i> • <i>Early prediction</i> • <i>Real-time detection and early warning of abnormalities</i> • <i>Warning of intervention and loss reduction</i> • <i>Realizing intelligent cold chain logistics with retrospective afterwards</i>
2	<p><i>Design of the IoT-CMS(Internet of Things-based cargo monitoring system)</i></p>	<ul style="list-style-type: none"> • <i>Effective storage guidance</i> • <i>Enhancing effectiveness of warehousing operations</i> • <i>Increased overall customer satisfaction</i> • <i>Maximizing product visibility.</i>
3	<p><i>Proposed framework for Cold Chain Management using Internet of Things (IoT) combined with other Industry 4.0 technologies</i></p>	<ul style="list-style-type: none"> • <i>supply chain visibility</i> • <i>optimised management and interpretation of generated data</i>
4	<ul style="list-style-type: none"> • <i>proposed a cold chain monitoring system based on wireless sensors and cloud</i> • <i>Lays the foundation for future projects on automating things using IoT</i> 	<ul style="list-style-type: none"> • <i>Improved and enhanced way to monitor the chain</i> • <i>A complete monitoring and end-to-end visibility.</i>

5	<i>monitoring and decision system based on wireless sensor networks (WSN) and ontology</i>	<ul style="list-style-type: none"> • Optimised assessment results of cold chain quality • Better monitoring of the supply chain • Efficient decision making
6	<i>IOT and CLOUD based platform</i>	<ul style="list-style-type: none"> • Real time monitoring • High efficiency and customer satisfaction.
7	<i>Development of a system using IoT of things that will make vaccine supply chain more flexible and adaptive.</i>	<ul style="list-style-type: none"> • optimize the supply routes of vaccines distribution • more flexible and adaptive vaccine supply chain • Efficient decision for stakeholders by offering timely information • Reducing the wastage cost of vaccines
8	<i>Development of an automation system assisted with IoT technologies to obtain timely temperature and humidity data</i>	<ul style="list-style-type: none"> • capturing the real-time condition of products during delivery • enhance product safety, operational efficiency, and customer satisfaction
9	<ul style="list-style-type: none"> • Construct an overall framework and hardware of the cold chain logistics quality perception base on the Internet of things • Designs and implements the hardware system and software system of the cold chain logistics framework 	<ul style="list-style-type: none"> • effective real-time collection and transmission of the cold chain logistics quality perception
10	<i>Development of a cold chain traceability system controlled via the Internet of Things technology</i>	<ul style="list-style-type: none"> • Better traceability • Provide managers with a convenient way of monitoring • Obtain real-time and historical information.
11	<ul style="list-style-type: none"> • Literature review on the IoT-based health care services from papers published until 2018 • Presents IoT applications in health care service delivery and outlines the critical challenges 	<ul style="list-style-type: none"> • Improving performance • Reducing costs • Real-time visibility and traceability
12	<i>Monitoring and managing animal vaccine supply chain relying on the Internet, integrating Internet of Things temperature sensing technology, RFID technology, network communication and other technologies</i>	<ul style="list-style-type: none"> • Make the animal vaccine cold chain monitoring more reliable • Ensure the quality and safety of vaccine transportation improved the overall social benefits and economic efficiency
13	<i>Proposed framework of an Internet of Things (IoT) sensor-based Blockchain</i>	<ul style="list-style-type: none"> • Mitigate the problem of counterfeit drugs • Properly monitor the cold chain for temperature specific drugs

14	<i>Development of an innovative monitoring of refrigerated storage systems.</i>	<i>Safe transportation of temperature sensitive medicines, vaccines, and biological samples</i>
15	<i>a real-time solution for pharmaceutical cold chain monitoring using Arduino based wireless sensor network</i>	<ul style="list-style-type: none"> • <i>Provide the information about storage environments in the cold chain in real time</i> • <i>More visibility of the chain from the manufacturing to the final distribution stage.</i>
16	<ul style="list-style-type: none"> • <i>Proposal of a GPS module and an IOT based sensor platform</i> • <i>Cold chain supply logistics are poorly coordinated, resulting in negatively influencing the safety of vaccines and other pharmaceutical items</i> 	<i>Better tracking and visibility</i>
17	<ul style="list-style-type: none"> • <i>An application framework for smart cold chain management system based on Hadoop, Spark and IoT (Internet of Things) techniques.</i> • <i>Enables users to develop and apply cold chain management systems with low cost and in short time, and to use any type of IOT devices</i> 	<i>Optimised Cold chain management</i>
18	<i>Design of NB-IOT wireless communication technology system</i>	<ul style="list-style-type: none"> • <i>Better monitoring of the position, status and safety of all reefer containers equipped with the intelligent terminal control.</i> • <i>Better transparency and hence efficiency of the cold chain</i>
19	<i>Cloud-based continuous monitoring application for supervising the operation of the vaccine supply chain.</i>	<ul style="list-style-type: none"> • <i>real-time remote monitoring.</i> • <i>long-term monitoring or</i> • <i>to track supplies,</i> • <i>providing the operator with real-time information</i>
20	<i>WSN-IoT (Internet of Thing based on Wireless Sensor Network) monitoring system for reefer containers is presented.</i>	<i>help workers to find abnormalities on container function in a short time using the web APP.</i>
21	<i>Design of a low-cost, single-use RFID based temperature threshold sensor.</i>	<i>Better temperature monitoring</i>
22	<i>Sensor Cloud application using Internet of Things</i>	<ul style="list-style-type: none"> • <i>Enhanced data visibility</i> • <i>Better management and product handling.</i> • <i>Better monitoring of the cold chain logistics ·</i> • <i>Low cost solution</i>

23	<ul style="list-style-type: none"> Review the technologies used for monitoring. The most commonly used technologies are: RFID, wireless sensor networks, internet of things and computerization in the cloud. 	Better Monitoring in cold chain
24	The paper presents the basics of the IoT and its applications in logistics and the supply chain, with a focus on its use in the Pharmaceutical industry.	<ul style="list-style-type: none"> Better quality control, Enhanced shipment tracking

The literature suggests that the main benefit of using internet of things technologies in the cold chain supply chain is improved monitoring and real time decision making. The benefits of IoT in supply chain management are prominent in enhancing the visibility and transparency of supply chains. Furthermore, stakeholders and customer satisfaction are valuable advantages of the use of IoT in cold chain logistics, where IoT technologies provide real time and accurate data for a better decision making process and a better visibility of the value chain.

4. Conclusion

In view of the pandemic crisis we are living, many new challenges and hurdles in the supply chain field have emerged. The cold chain management has now become a crucial knot in the SCM field, considering its necessity in the vaccine transportation. This review tried to map the existing research and models exploiting the IoT in the cold chain management.

The main benefit of IoT in the CCL is an optimised monitoring and tracking of the supply chain as well as a better real time decision making process. The literature points out a lack of involvement of IoT in vaccine supply chain management, affirming that this scope of research is still nascent. This review will serve as a guidance and research agenda for the researchers and professionals that are interested in contributing in the advancement of the cold chain logistics by taking advantage of the internet of things technologies.

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Appendices

Code	Reference	Title
1	(Tao et al., 2019)	<i>A medicine cold chain monitor system based on LoRa wireless technology</i>
2	(Tsang et al., 2017)	<i>An IoT-based cargo monitoring system for enhancing operational effectiveness under a cold chain environment</i>
3	(Khanuja et al., 2018)	<i>Cold chain management using model based design, machine learning algorithms and data analytics</i>
4	(Chandra, 2014)	<i>Advanced Monitoring of Cold Chain using Wireless Sensor sing Wireless Sensor Network and Sensor Cloud Infrastructure</i>
5	(Wang et al., 2015)	<i>Developing an ontology-based cold chain logistics monitoring and decision system</i>
6	(Marinelli et al., 2021)	<i>An Explorative Analysis of IoT Applications in Cold Chain Logistics</i>
7	(Daniela Antal et al., 2015)	<i>Efficient Vaccine Distribution Planning using IoT</i>
8	(Wu et al., 2020.)	<i>Experimental Investigation of A Real-time Monitoring System for Cold Chain Logistics</i>
9	(Luo et al., 2018)	<i>Research on Signal Intensity and Distance in Cold Chain Logistics Data Acquisition</i>
10	(Chen et al., 2017)	<i>Design of Cold Chain Traceability System Based on Internet of Things</i>
11	(Usak et al., 2019)	<i>Health care service delivery based on the Internet of things: A systematic and comprehensive study</i>
12	(K. Zhang et al., 2019)	<i>Internet of Things Technology in Animal Vaccine Cold Chain Management.</i>
13	(Singh et al., 2020)	<i>Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention</i>
14	(Bengiovanni et al., 2020)	<i>Risk Management and Healthcare: IoT Technologies and Smart Monitoring System for a Good Cold Chain Management</i>
15	(Jong Ro Lee et al., 2020)	<i>Internet-of-Things Based Approach for Monitoring Pharmaceutical Cold Chain</i>
16	(Mohsin & Yellampalli, 2018)	<i>IoT based cold chain logistics monitoring</i>
17	(Ko et al., 2015)	<i>Design of Smart Cold Chain Application Framework Based on Hadoop and Spark</i>
18	(N. Zhang et al., 2019)	<i>NB-IOT Drives Intelligent Cold Chain for Best Application</i>
19	(Daskalopoulos et al., 2014)	<i>Policy-enabled Internet of Things Deployable Platforms for Vaccine Cold Chains</i>
20	(Tang et al., 2019)	<i>Reefer Container Monitoring System</i>
21	(Bhattacharyya et al., 2014)	<i>RFID tag antenna based temperature sensing in the frequency domain</i>
22	(Raju & Jaya Sri, 2017)	<i>Sensor Cloud to Monitor Cold Chain Logistics using Internet of Things (IoT)</i>
23	(Campos et al., 2018)	<i>Technologies applied in the monitoring and control of the temperature in the Cold Chain</i>
24	(Jain & Sharma, 2020)	<i>Transforming pharma logistics with the Internet of things</i>