Vol. XVI & Issue No. 12 December - 2023
INDUSTRIAL ENGINEERING JOURNAL

DESIGN OF COLD SUPPLY CHAIN FOR PERISHABLE FOOD PRODUCTS FOR IMPROVING THE DIMENSIONS OF SUSTAINABILITY

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Abstract

Perishable Food Cold Supply Chain Management (PFCSCM) requires a vast amount of data to be collected and analyzed continuously. Recent developments in the Internet of Things offer significant benefits to the PFCSCM and help improve overall business performance and objectives of sustainability. This paper discusses advances in the perishable food sector concerning control engineering. The PFCSCM is broken down into four steps: Production, Processing, Storage, and Delivery. Further, the use of radio frequency identification (RFID) for traceability of PFCSSM is discussed. In addition, a conceptual framework is proposed for low-cost, sustainable, and eco-friendly PFCSCM, specifically for the business-to-customer (B2C) service model. Finally, cost analysis is performed to validate the proposed framework.

Keywords- Cold supply chain, RFID, Sustainability, Cost analysis

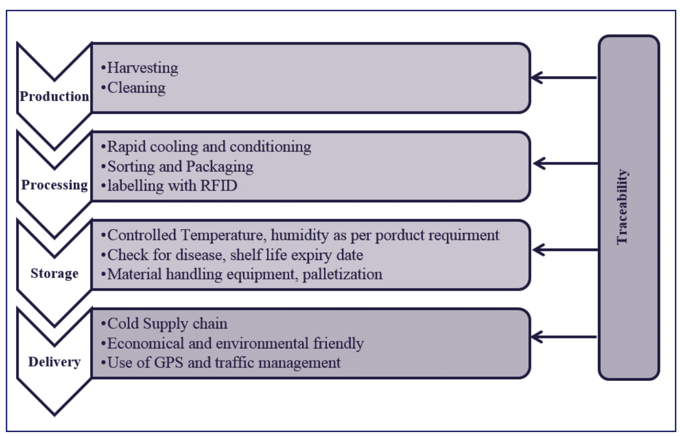
1.0 INTRODUCTION

Agricultural and Farm products are of greater importance in day to day life of urban living (Raut et al., 2019). Since these products (fruits, vegetables, dairy, meat, etc.) have a smaller shelf life, there is a need to sort, process, store, and deliver the products with immense care. If not done properly it may lead to food wastage (Gokarn and Choudhary, 2021). As per the World Health Organization (WHO) and Food and Agriculture Organization (FAO), pre-consumer food losses are the main cause of food losses and waste. The increase in population has led to increased demand for perishable food products such as fruits, vegetables, dairy, meat, etc. (Kumar and Choubey, 2023). The parameters such as harvest time, temperature, humidity, shelf life, exposure to direct sunlight, and procedures performed play a significant role in the life of perishable products (Abbas et al., 2023). This huge chunk of data needs to be saved and should be easily accessible. Also, an increase in population leads to a rise in the demand for products. Further, the increase in cold storage and supply chain energy requirement caused a rise in environmental adverse effects (Narwane et al., 2022). There is a need for sustainable management of perishable food products. Advances in the Internet of Things (IoT), sensors, AI/ML, and Industry 4.0 are a boon for the management of these perishable food products (Kumar et al., 2022). The main purpose of the study is to address the increasing demand for perishable food supply. The increasing population further creates more demand for food. In a view to manage food availability, it is high time we start using a perishable food cold supply chain management system. The main objectives of the study are to find the most probable solution for the Indian perishable food management system and the sustainable development of the unorganized sector. This paper aims to concentrate more on the B2C service model and utilize the above-mentioned advances to increase profitability and thus reduce wastage in perishable food products. The manuscript is organized as follows. Section 2 gives the background of the study followed by the proposed model in Section 3. Section 4 discusses cost analysis and the conclusion of the study is given in Section 5.

2.0 BACKGROUND OF THE STUDY

Management of food products right from the farm to the consumer requires continuous monitoring of various parameters. For ease of understanding, a complete perishable food product management system can be broken down into the following steps as shown in Figure 1.

Figure 1: Perishable Food Product Management System [Source: Author]



The above-mentioned steps may vary from product to product and can elaborated as follows.

***2.1 Production*:** The shelf life of the product majorly depends on the quality of the product, thus the product harvested should be of the required grade and quantity. Nowadays farmers have moved towards new methods to grow a standardized and quality product. Many have started using greenhouses to cultivate food products. Bajer and Krejcar (2015) have designed a low-cost device to control the greenhouse environment using Arduino, sensors, and actuators remotely, also a website to monitor and display environmental conditions. Datir and Wagh (2014) developed a time system to detect Downy Mildew pest in grapes using WSN based on weather data in real-time, using actuators could spray pesticides automatically wherever required, which reduced the cost of pesticides required there in cost of production and enhanced the quality and quantity of grapes. Witjaksono et al. (2018) presented the idea of using the Internet of Things (IoT) for agriculture and food quality. He devised a mobile application as the sensing layer of the IOT technology. The app detects the freshness of food with the help of images of the product and compares it with the reference image. The data collected can be shared right from the farmer to the consumer. Advancements in many technologies can help farmers in a vast number of ways. IoT along with AI/ML can tell right from the correct time to sow seeds to the harvesting also it can detect pests if any and suggest the pesticide to be sprayed. The main aim of all this is to get good quality produce, for getting comparatively long shelf life.

***2.2 Processing*:** As shown in Figure 1, the Processing of perishable food products involves rapid cooling, conditioning, and packaging for the customer. Processing, simply stated, involves the changing of raw materials, such as vegetables or milk, into ingredients such as salad and dairy products. This is also known as the manufacturing or value addition stage. With the increasing demand for safe and high-quality food products and increasing consumers all over the world, there needs to be implementation of new technologies in processing. Precooling and humidity content plays a very important role in the shelf life of a product. Standardizing and grading processes to improve quality assurance in the perishable food supply chain was proposed by Leung et al. (2020). Segregation of products will ease handling and environment control for a longer shelf life.

***2.3 Storage*:** Feng et al. (2020) have successfully utilized IoT - an enabled monitoring system with an electronic nose detection system utilized for detecting the freshness of salmon. They developed a sensor-based wireless network to check the freshness of salmon in cold storage. An electronic nose is an array of sensors to sense different types of molecules in the air. Along with the Electronic nose, the other environmental data were combined to get an output of the freshness of the salmon. The overall accuracy was found to be more than 90%. This showed an increase in the shelf life of salmon by controlling the temperature.

***2.4 Delivery*:** Due to the recent bloom in perishable food supply chain management, compared to traditional freight forwarding practice e-Commerce can operate in four different modes, namely business to customer (B2C), business to business (B2B), business to business to customer (B2B2C) and customer to customer (C2C). Tsang et al. (2021) combined multi-temperature joint distribution and e-commerce logistics for managing perishable food e-commerce logistics effectively. They developed an IoT-based Multi-Temperature Delivery Planning System integrating IoT technologies, multi-objective optimization, and fuzzy logic. IoT system eases it to gather information on the supply chain environment data without human intervention. As will be discussed in traceability, it also helps in tracking of the specific products. Dynamic routing system was also developed and the advantages of the system were discussed. Static routing will support the transportation team in planning before delivery, on the other hand, dynamic routing will be helpful during unexpected incidents such as order cancel, new order placed, traffic, etc.

***2.5 Traceability*:** Traceability is the most critical function of the PFCSCM, which provides the location of the product along with its environmental measurements. It is very helpful for both the end user and the supply chain managers. Customers can keep track of the freshness of food and track it at the same time; similarly, the supply chain managers can control the environment as per requirement remotely. Customers who believe in the physical testing of products can be diverted to the online market with the help of traceability functions along with environmental measurements. A traceability system can track and record the location and the environmental conditions from source to sink. Tsang et al. (2019) formulated an IoT technology framework with blockchain and fuzzy logic for traceability and quality evaluation of food from source to sink. IoT technology helps in continuous environment sensing without human intervention and helps to control the environment of the supply chain. It is a cost-effective way of measuring the environmental conditions. All the data that is measured is collected and managed by a cloud server, and traceability data is stamped in the blockchain. The method developed is beneficial but incurs a high initial cost due to the high cost of the sensor and the WSN system.

***2.6 RFID Sensors*:** RFID (radio frequency identification) is a device used for tagging an object by a certain ID and detecting it with the help of Radiofrequency. They are made of tiny transponders of unique ID which can transfer the data over RF. Three types of RFID are passive, semi-passive, and active. Passive tags do not require any power source and consist of a microchip with an antenna. They transmit the data by backscattering, i.e. RF induced into the antenna generates a current that is utilized to respond to the signal. They are small and very cost-effective, but the drawback is that they can be read within a range of 2mm to a few meters. Semi-passive tags are passive tags with an internal power source only for powering the chip and not for signal response. Due to the internal power supply, the antenna can utilize all the energy received by it for backscattering. Active tags on the other hand are powered by external supply. Energizing the microchip and generating a response signal. Even though the range of active tags is up to 10 meters it is a costly affair compared to the other two tags. Honari et al. (2018) have shown that RFID sensors can be used for early expiry detection of packaged foods. The RFID sensor proposed by them was a carbon-based sensor that can detect a specific compound as it varies the conductivity of current through it. It was also proved by them that this can be very well carried out with the help of a passive RFID sensor. The sensor proposed by them can be used in many applications related to perishable food products. It was a simple, inexpensive method applicable to many products. Tan et al. (2019) and Shafiq et al. (2019) described different applications for cost-effective measurement of temperature with the help of embedded RFID sensors. The experiment demonstrated that the proposed sensor tag can provide reliable performance in wireless concrete temperature measurement. Borgese et al (2017) devised an inkjet printer chipless RFID sensor for wireless humidity monitoring. Low-cost, flexible method to measure humidity. A novel chip-less RFID humidity sensor was made and tested. A conductive ink was printed on a cardboard substrate and used without any curing, thus trying to reduce the cost and time of manufacturing. The change in humidity causes rise and fall of moisture in the cardboard thus leading to change in the frequency of transmission. Measuring the frequency humidity level of the environment can be calculated with high sensitivity. Above above-discussed papers depict the huge scope of RFID-based IoT in CSCM. Development in the field of RFID tags will pave the way for further development in CSCM.

3.0 PROPOSED MODEL

This study aims to focus mainly on the B2C delivery model utilizing RFID sensors. As discussed above the supply chain can be divided into enlisted steps and this study focuses on the delivery model only. To provide a sustainable and cost-effective solution for the perishable food cold supply chain.

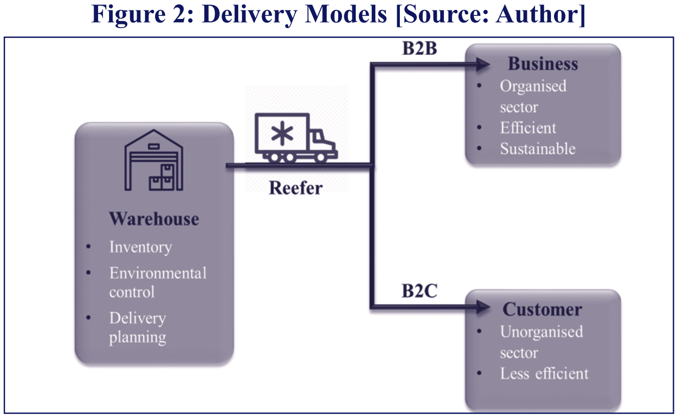
Following are the assumptions made for the proposed model.

i) *Product Segregation*: It is assumed that the products are segregated for attaching the RFID tags properly. Also, the segregation can be done in various ways such as Daily Essentials (milk, bread, egg, etc. depending on the customer); and Weekly Essentials (fruits, vegetables, meat, etc.). This will further enhance sensing, shelf life management, and tracking.

ii) *Automated packaging*: Segregated products can be packed with the help of robots since they are repetitive work. The placing of RFID sensors can be automated along with ease in packaging. Quick loading and unloading due to palletization will reduce ETA.

iii) *Shelf life management*: Proper cold storage functioning, to increase the shelf life.

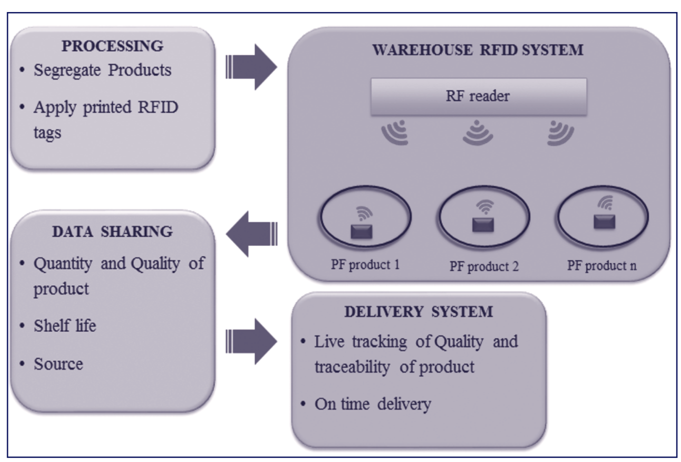
Figure 2: Delivery Models [Source: Author]



As shown in Figure 2, the B2B model is an organized sector that manages the perishable food supply chain with efficiency and sustainability. On the other hand B2C model in India is not as well developed as required, mainly due to the added cost in supply chain and management. The traditional method of same-day perishable food delivery is preferred, even though it causes massive losses in food and volatility in prices. In the age of population growth with major food loss, it is very well advised to move towards a B2C supply chain. The model proposed utilizes printable passive RFID-based sensors, to measure the following basic parameters humidity, temperature, and perishability/shelf life. As seen in the literature review, RFID sensors that measure the above parameters have been designed. And that those sensors are at par with other IoT sensors connected to wireless sensor networks. These sensors will be a boon for Indian PFCSCM for the B2C sector, being very cost-effective and sustainable. These sensors can be printed directly on the containers or one-time use tags. RF reader will be placed at every node or wherever necessary. These readers will also generate an electromagnetic field to power passive RFID sensors. Every RFID sensor will have a unique ID number which will be transmitted along with the sensor data to the reader. The reader will further collect the data and store it on a cloud server. The data collected can be used for environmental control and measurement. While delivery the location of the product can be shared with the customer using GPS along with the other three parameters. Parameters measured and stored can be of greater use to gain the trust of new customers especially those who are new to online grocery shopping.

Figure 3 depicts the simple RFID system at every warehouse. All the above parameters will be read at the set period. As shown below the system consists of sensors in every product or a group of products. This will make sure that perfect reading is taken of every product. The sensors need not be collected back again unlike IoT-based wireless sensor networks. The main disadvantage of wireless sensor networks is the high initial cost and life cycle of the sensor. Printed RFID passive sensors are almost one-tenth the cost of active RFID sensors.

Figure 3: RFID Proposed Model [Source: Author]



4.0 COST ANALYSIS

Costs considered below are the average market costs of each product. Assuming that one reader setup covers the same area in all three types of methods. As can be seen from the above Table 1, the fixed cost for Active RFID is the highest. To find the break-even point between all the above methods, we can plot the graph.

Table 1: Cost comparison of different Models

Features	Analog RFID Sensor (a)	Active RFID Sensor (b)	BLE (c)
Power / attery	Not required	Required	Required
Sensor Cost (V)	₹ 100	₹ 1600	₹ 1600
Reader Cost (F)	₹ 30000	₹ 70000	₹ 2000

Considering the data in Table 1, break even analysis plot can be plotted as shown in the following Figure 4. The dotted horizontal line on the graph represents the fixed cost of the readers. And as an active RFID sensor has the highest cost of the reader, it has the highest fixed cost. On the other hand cost of the sensor is considered a variable cost which is directly proportional to the number of products, shown by the solid line. As can be observed from the graph, Passive RFID will be less costly compared to BLE and Active RFID if used when the quantity of sensors required is greater than 16 to 20.

Sensor cost of Active RFID and Passive RFID nearly being equal, the fixed cost factor plays a very important role in decision making. Since the above costs considered may vary, the required break-even point can be found by the formula method too.

Equating the total cost of the Passive RFID system and BLE system,

Equating the total cost of the Passive RFID system and BLE system,

$$Total\ Cost\ (Passive\ RFID) = Total\ Cost(BLE)$$

$$Fixed\ Cost\ (a) + Variable\ Cost\ (a) = Fixed\ Cost\ (c) + Variable\ Cost\ (c)$$

$$F_a + (V_a \times n) = F_c + (V_c \times n)$$

$$n = \frac{F_a - F_c}{V_c - V_a}$$

Where,

n : $number\ of\ sensors, i.e. number\ of\ products$

F_a : $Cost\ of\ reader\ for\ passive\ analog\ RFID$

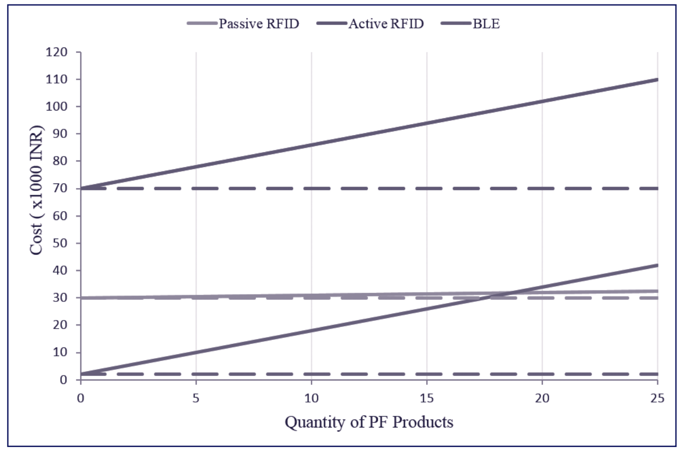
F_c : $Cost\ of\ reader\ for\ BLE$

V_a : $Cost\ of\ Sensor\ for\ passive\ analog\ RFID$

V_c : $Cost\ of\ Sensor\ for\ BLE$

The model proposed in this paper will be very cost-effective compared to other methods and the main reason for that is the least cost of RFID sensors. Even if the cost of BLE sensors reduces shortly, using RFID sensors will be much more efficient for the B2C model. The quantity diversity of products will be much more compared to the B2B model. And for this reason, using RFID analog sensors is the best option as seen from Figure 4.

Figure 4: Break-Even analysis of three types of IoT model [Source: Author]



5.0 CONCLUSION

Perishable food products management is essential due to faster-growing demand. The main aim of the proposed model was to make the PFCSCM cost-effective and sustainable, which is achievable. With proper management of the environmental conditions with the help of the proposed system, food wastage will reduce and thus reduce loss due to food wastage. Further RFID sensors can be printed on cardboards and packaging surfaces, thus making it more sustainable. Also proposed model will make it easy to attract new customers who are quality-conscious and prefer the physical market and make it easy for individual consumers to rely on the safety and quality of the perishable food delivered to them. As per the calculation done in the study, the RFID passive sensor-based model will be an optimum solution for the B2C model as the products will be large in quantity and variety. To arrive at a reliable conclusion, a physical model or simulation model should be generated and analysis be made. Advantages offered by the system are as follows: cost-effective implementation, decreased food loss, ultra-low power, miniaturized flexible devices, long life compared to semi-passive RFID and BLE/WSN system, sustainable supply chain management, and attracting quality conscious customers.

Implications of the study

- Real-time Parameter sensing and control through increasing the quality and data sharing with customer
- Shelf life sensing/calculation
- Real-time tracking for customers from order placed to delivery.
- Real-time stock display for product booking and inventory maintenance.
- Standardized product- Ease of delivery, ease of maintaining uniform quality
- Uniform packaging - Palletisation, ease of handling.

Limitations and future scope

The proposed conceptual framework could be implemented for an Indian PFCSCM. Also use of Artificial Intelligence (AI), Machine Learning (ML), and Big Data Analytics (BDA) can be explored.

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