

A Guideline for Enhancing F&B Quality Through IoT-Based Real-Time Temperature in Cold-Chain Process Flow

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DOI: <https://doi.org/10.47772/IJRISS.2026.100701118>

Received: 08 August 2026; Accepted: 13 August 2026; Published: 22 August 2026

ABSTRACT

Cold-chain process flow is crucial for preserving the safety and quality of perishable food products, especially in the food and beverage (F&B) industry. As time goes on, the supply chain has become more complex, and traditional methods often fail to effectively monitor temperature during transit. This issue has led to delays, temperature abuse, and negatively affects food quality, such as spoilage and contamination, which can pose serious risks to food safety. This paper aims to explore how the integration of IoT technology can help to improve real-time monitoring and operational visibility in cold-chain processes. The main objectives of this paper are to identify the IoT-enabled cold-chain process flow, the impacts of the process flow, and to propose practical guidelines for safer and more efficient cold-chain process flow practices in the F&B industry. A qualitative research approach is used which is combining semi-structured interviews and structured observations to gather data from industry practitioners. While the results are still in progress, this study presents a conceptual foundation for the implications of IoT with an understanding of how it can practically improve food quality, safety, and compliance. The expected results are to develop future cold-chain guidelines to better communicate, coordinate, and manage disputes and risks related to the F&B supply chain processes.

Keywords- Cold-chain, Food and Beverage, IoT, real-time temperature, supply chain

INTRODUCTION

This paper introduces the cold chain process flow and the application of IoT technology to preserve the safety and quality of food. An introduction to cold-chain logistics will be provided along with a list of its key elements, including handling facilities, cold transport systems, and temperature-controlled storage. Additionally, this paper highlights the importance of preserving perishable goods and the ways in which cold-chain systems impact food safety and quality, particularly in Malaysia's F&B industry. Finally, this paper will examine how IoT can be used for cold-chain monitoring, including the application of smart sensors, the advantages of real-time monitoring, and the implementation challenges.

LITERATURE REVIEW

Overview of the Cold Supply Chain

A temperature-controlled supply chain that provides a variety of facilities to adhere to various temperature requirements to maintain ideal quality products. It also covers the period from the point of origin till it reaches the end-consumer in the ideal conditions wanted (Tsai & Pawar, 2018). The focus of this technology is to ensure products stay within their required temperature needs from the point of producer till reach the consumer (Han et al., 2021). Refrigerated vehicles, refrigerated display cabinets, controlled atmosphere storage

warehouses, pre-cooling facilities, and consumer refrigerators are essential components of the cold supply chain infrastructure that help prevent temperature instability of perishable products (Khalid et al., 2024). Thus, temperature-controlled supply chains continue to be necessary for the safe transportation and storage of food items after harvest.

Perishable goods can now be tracked and their temperature and humidity levels monitored throughout the supply chain, extending their shelf life thanks to modern technologies (Huang et al., 2023). For perishable goods to remain safe and of high quality, cold storage facilities are crucial. They act as main locations where goods are maintained at desired temperatures before being delivered to stores or customers. Even the most advanced transportation systems might not be able to preserve the quality of the product if storage conditions are not proper.

Cold storage infrastructure, such as refrigerated warehouses and pre-cooling facilities, is crucial in avoiding temperature swings that could affect product freshness (Mustafa et al., 2024). On top of that, it is also crucial to include not only food processing and cultivation but also packaging, handling, storage, and distribution by using technologies to monitor the whole supply chain process to ensure good quality (Huang et al., 2023).

Key Components of the Cold Supply Chain

The cold supply chain, which is also commonly known as cold-chain, is a part of the supply chain process that involves storage, transportation, and handling of temperature-sensitive products. The main goal is to maintain a constant temperature within a required range from the point of origin to the destination, which is to prevent any product spoilage, contamination, or loss of efficacy

Temperature-Controlled Storage Facilities

The first one is temperature-controlled storage. This storage is crucial to preserve the quality and safety of perishable products during the process of supply chain. These facilities, like cold rooms and refrigerated warehouses, can ensure that they maintain a specific temperature range to prevent any spoilage of the products. In addition, Iyer & Robb (2025), they stated that the significance of efficient temperature-controlled storage is highlighted by cold chains, which are specialized supply chains created to maintain the quality of temperature-sensitive products from procurement to fulfilment.

For example, to prevent bacterial growth and spoilage, perishable food and beverage items like fresh dairy products, seafood, and ready-to-eat meals need to be stored at an accurate temperature. Generally speaking, these goods need to be kept between 0°C and 4°C. Studies reveal that up to 30% of chilled food is thrown out as a result of inadequate temperature control in storage facilities, indicating that poor temperature management during storage in the F&B cold chain can result in serious quality decline and illness caused by food risks (Ndraha et al., 2018).

Cold Transport Systems

Cold-transport systems mostly include refrigerated trucks and containers that are engineered to maintain and preserve temperature-sensitive products during the transportation process. To maintain the necessary temperature ranges, these systems frequently use refrigeration units that run on diesel generators or other energy sources. Transport systems are incorporating innovations like Phase Change Materials (PCMs) to improve thermal efficiency and lower energy consumption (Calati et al., 2022).

PCMs are one type of cold transport system that will be discussed. To help maintain a constant temperature in storage units or transport boxes without the need for continuous mechanical cooling, PCMs absorb or release heat when they change states, such as from solid to liquid. They can be used in vaccine transport boxes or refrigerated trucks because PCMs can maintain a consistent internal temperature even when outside temperatures change (Calati et al., 2022).

Handling Facilities

Handling facilities are crucial parts of the cold supply chain for food and beverage (F&B) products as they move between various cold chain stages, such as from warehouse to retail outlets or from transport to storage. Receiving bays, cross-docking terminals, and distribution centres are examples of handling facilities in the cold supply chain. Transfers such as unloading frozen meat or seafood can result in the exposure of the product to ambient conditions for minutes or even seconds, which can cause an initial thaw on the surface of the frozen product, reducing shelf life and increasing the potential for bacterial contamination (Aung & Chang, 2014; Deng et al., 2021).

As an example, simply exposing it to room temperature during the unloading of frozen meat or seafood can result in surface thawing, leading to shorter shelf life and raising the possibility of bacterial contamination. Aung & Chang (2014) state that improper handling of temperature changes can result in a 15% reduction in the quality of perishable food items.

Importance of Preserving Perishable Goods

Perishable goods are sensitive to temperature change, humidity, and handling conditions during transportation and storage. These conditions have a major impact on the products' nutritional value, texture, shelf life, and microbiological safety. Product spoilage, illness caused by food, and financial loss can result from any disruption of the cold chain, even if it is only temporary (Ndraha et al., 2018).

Therefore, due to the goods' sensitivity to temperature change, it is crucial to have continuous monitoring during the transportation process to ensure goods quality. Fruits, vegetables, seafood, meat, and dairy products are among the perishable goods whose quality is greatly impacted by the way they are stored and transported (Khalid et al., 2024). Losses that could result from incorrect handling and unmonitored temperature during transit can be avoided by preserving and maintaining the quality of the product.

Therefore, it is crucial to continuously monitor the temperature during the logistics process to ensure and guarantee the best possible preservation of the goods during transportation. Real-time monitoring tools like RFID sensors, GPS tracking, and Internet of Things-enabled temperature loggers help in identifying and fixing cold chain incidents before harm is done. The way perishable goods are stored and transported has a direct impact on their quality, as stated by (Khalid et al., 2024).

Impact of Cold Chain on Food Safety

Food safety is crucial to all business owners during transportation because there might be inevitable problems occurs during the process. Therefore, maintaining a reliable cold chain is crucial in the F&B industry to ensure food safety and prevent any product contamination. By maintaining perishable goods within safe temperature ranges, the cold chain reduces microbial risks and guarantees adherence to safety and legal regulations that control the handling and transportation of food.

Temperature Abuse and Microbial Risks

Temperature abuses are mostly refers to food products that are being exposed to conditions outside of their required temperature range. Due to this, there is a high probability of microbial growth on the products, which can cause more health issues for the consumer. According to Ndraha et al. (2018), one of the most significant factors causing microbial risks and food spoilage is time-temperature abuse during storage, transit, or retail handling. It also highlights how human error, poor handling techniques, and insufficient monitoring systems are frequently the primary causes of temperature abuse incidents throughout the process. Mataragas et al. (2006) found that temperature abuse during storage can help the growth of *Listeria monocytogenes* to a level where it could increase health risks. This shows that it is important to maintain proper storage temperatures to prevent any microbial spread towards the perishable goods.

These studies have mentioned that maintaining strict temperature control for perishable goods is important to mitigate any microbial risks and ensure customer health safety. By ensuring these aspects, an organization able to ensure these aspects, a company may maintain product quality, comply with regulations, lower the possibility of product recalls, and enhance customer confidence and brand recognition in the marketplace.

Regulatory and Safety Standards

In the F&B industry, compliance with legal and safety standards is crucial and essential to ensure that customer health and maintain product integrity throughout the supply chain process. The regulations made can provide the foundation for managing food safety to mitigate risks, especially for temperature-sensitive goods that require strict cold chain handling.

In Malaysia, the primary legal framework that governs food safety is the Food Act 1983 and Food Regulations 1985. Both laws have been enforced by the Ministry of Health (MOH), which covers several critical areas in food safety such as hygiene practices, temperature control, food labelling, and microbial limits. If an organization or a company does not comply with the regulation, there would be consequences such as fines, product recalls, or even business suspension by the ministry (Ministry of Health, 2014).

Other than that, there is also the Hazard Analysis and Critical Control Points (HACCP) system that is widely implemented in the food safety framework. This framework has been widely used in the F&B sector, which functions to identify and control any biological, chemical, and physical hazards at the critical point during the food production process. According to Awuchi (2023), it has been emphasized that the HACCP system has become a legal requirement in a lot of countries, especially in countries involved in the handling, processing, and distribution of high-risk foods. Many governments and food authorities, such as Malaysia's Ministry of Health, require businesses to follow the HACCP system to ensure that food safety risks are properly identified and controlled at every step of the process.

Food Quality Challenges in the Cold-Chain F&B Industry

In the F&B business, cold-chain systems oversee maintaining the safety and quality of perishable food products. However, several factors, including fluctuations in temperature and microbial contamination, can still affect food product quality at different points in the cold chain. These issues have been the organization's main concern since they might lead to not only monetary losses but also health hazards for customers and compromise the integrity of the product. Due to inadequate quality control across the supply chain systems, it will also result in a decline in the product's perceived value from the perspective of the customer.

Typical Food Quality Issues in Cold-Chain Process Flow

Several common problems with food quality arise throughout the supply chain process. Temperature fluctuations occur during the supply chain process. Because perishable food goods have specific temperature requirements, temperature abuse is one of the most important challenges. This is also because cold-chain process flow degradation in quality is easily caused. Perishable items like dairy, seafood, and meat products can be significantly impacted by temperature changes, even if they are just temporary. For instance, frozen foods that have been exposed to temperatures below -18°C and have thawed before being refrozen again may experience nutritional loss and texture degradation (James & James, 2010). Similarly, further studies conducted on blueberries in 2024 by Fu et al. (2024) show how improper temperature handling might increase decay, perhaps interfere with firmness, and lower their nutritional value.

Apart from that, microbial growth is the cause of most quality issues. Inadequate temperature control may encourage the growth of microorganisms that affect perishable food items. According to research, strawberries subjected to temperature changes during the cold-chain process show a load of microbial development, including yeast and mold growth, which may negatively impact the food's quality and flavour (Kelly et al., 2021). This has brought attention to the need for temperature control in reducing microbiological risks during the distribution process and averting potential health problems brought on by insufficient temperature control.

Finally, it will shorten the perishable items' shelf life. The shelf-life of perishable goods may be shortened by inconsistent temperature control management. According to research on blueberries, improper storage temperature has resulted in a considerable decline in quality, including various physical changes to the fruit's texture, colour, and nutritional content (Fu et al., 2024). This decline in perishable items' quality might limit the fresh produce's marketable duration, increase food waste, and perhaps cause financial losses.

Root Causes of Food Quality Issues

It is known that it is a challenge to maintain the integrity of the cold chain to ensuring to preserve the quality and safety of perishable food products during the whole supply chain process. However, due to several factors that lead to food quality issues, it is crucial to figure out the primary root cause of food quality issues in the supply chain.

First, due to a lack of real-time temperature monitoring systems. The cold supply chain's lack of real-time temperature monitoring puts product quality and safety at serious risk, resulting in financial losses and reduced consumer confidence. The growing complexity of cold chain operations, which require strict temperature control during storage and transit, makes this problem worse. To prevent spoiling, real-time temperature monitoring makes sure that perishable goods, such as food and medications, are transported and kept within acceptable temperature ranges. It also helps to enhance visibility across the supply chain to allow any timely interventions to minimize financial losses and optimize the logistics process (Wanganoo & Shukla, 2020). Real-time monitoring is necessary for guaranteeing the safety and quality of perishable items because it enables quick detection and reaction to environmental changes. Particularly for delicate goods like food items and medications (Vlakh-Vyhrynovska et al., 2023), temperature changes, even for a short time, can cause a fast and unpredictable process of spoiling.

Secondly, it is known that poor post-harvest handling and packaging are one of the root causes of food quality issues. Perishable foods, including fruits, vegetables, seafood, and dairy products, begin to degrade as soon as they have been harvested due to both physical damage and contamination, which can be even further aggravated due to poor handling and packaging (Kosgi et al., 2025). Physical injury such as bruising and cuts that occur during transport, sorting, cleaning, and packing can disrupt their natural barriers against microbial growth and/or enzymatic spoilage (Kosgi et al., 2025). Moreover, if the packaging is non-standard or damaged, which compromises moisture and oxygen protection, factors in the environment will hasten the quality loss (Kosgi et al., 2025). These handling and packaging failings mostly occur at the early stages of the cold chain, which can lead to enough degradation that cannot be undone later in transport or retail.

Lastly, supply chain fragmentation and lack of coordination. A lack of coordination or communication among stakeholders such as producers, handlers, transporters, and retailers can easily lead to misalignment in timing, misalignment in inventory, and misalignment in temperatures that can result in a decrease in food quality (Sanni, 2024). In the absence of synchronized scheduling and visibility, shipments can be delayed or documents held, with little to no refrigeration, causing increased spoilage issues and microbial contamination possibilities (Sanni, 2024). However, there are examples of studies demonstrating how synchronization with effective parameters utilizing IoT products like temperature sensors, cloud platforms, and real-time data updates can help to establish better coordination, where the spoilage rate is reduced, and product quality and compliance are improved (Sanni, 2024).

To summarize, addressing food quality in the cold supply chain requires finding the main root causes, including the lack of real-time temperature monitoring, inadequate post-harvest handling and packaging, and the lack of coordination among cold-chain users. These issues degrade perishable food items' safety and freshness, which are causing food losses, financial losses, and less consumer confidence. Once the food and beverage industry acknowledges the value of the root causes, they can plan strategically, either utilizing advanced IoT technologies and better coordination within the cold chain, and ultimately, improve cold-chain performance and high-quality food products.

Cold-chain process flow Practices Using IoT in the F&B Industry

Real-time food temperature and quality monitoring have been significantly impacted by the integration of Internet of Things (IoT) technologies into cold-chain operations. IoT offers the ability to monitor remotely and to collect automated data collection to make sure perishable goods don't go beyond the supply chain's safe temperature limitations. IoT in cold-chain process flow improves traceability, lowers waste, and boosts consumer confidence in addition to ensuring safe food.

Smart Sensors

Smart sensors integrate sensing elements, microcontrollers, and wireless transmitters to manage the collection and preprocessing of data, like temperature, humidity, and shock, before transmitting it to a network or cloud structure (Ramírez-Faz et al., 2020). However, internet usage is not always feasible for smart sensors in food storage conditions, but smart sensors can use communication standards, like Zigbee, Bluetooth, Wi-Fi, GSM, and LPWAN, to maintain an adequate level of connectivity across the storage facility and vehicles. The low-power and self-calibrating functions of smart sensors help enable deployment at scale, with the ability to deploy smart sensors in cold environments to allow for better monitoring (Ramírez-Faz et al., 2020).

Cloud-Based IoT Platforms

Cloud platforms provide a centralized system for performance, telemetry, monitoring, storage, analysis, and visualization of sensor-generated telemetry. Sensor or telemetry data is sent to the cloud, where the platform logic and alerts, as well as dashboards, are used to provide remote monitoring coordination and proactive decision-making (Ramírez-Faz et al., 2020). Commercial and open-source IoT platforms, such as Azure IoT Hub, FIspace, and custom integrations, enable organizations to manage devices, set thresholds, and analyse historical trends, further supporting cold-chain resiliency and improved traceability in data sharing.

Real-World IoT Practices in Cold-chain Process Flow

IoT technology is already being utilized in cold-chain process flow at the larger scales of some F&B retail operations in Malaysia. An example of this is Mydin Mohamed Holdings Bhd's implementation of UST's "Cold Truth" solution to enhance its temperature monitoring system for cold stores and chiller units. In this system, IoT sensors are continuously collecting temperature data and sending it to a cloud platform. The solution's capability will send alerts via real-time SMS or email messages to relevant personnel when any deviations occur outside of the acceptable temperature ranges. Not only does having an IoT solution in this situation reduce reliance on manual temperature recording, but it also allows for improved traceability and compliance with food safety measures, for example, replacing HACCP standards (UST, 2013).

Another example of localized IoT is the ETCCC Cold-Chain Cloud Platform from ExcelTest, a Malaysian technology firm, which is being used by small-to medium-sized F&B (Food & Beverages) producers and frozen food distributors to track temperature, humidity, and location in real-time along the supply chain. The system couples wireless data loggers, cloud dashboards, and GPS tracking for full visibility of the storage and transportation environment. In the event temperature breaks occur, automated alerts are dispatched to the personnel responsible, and all the data are archived for audit or quality review (ExcelTest, 2023). This enables food companies to anticipate spoilage and maintain cold-chain compliance, as fresh and perishable foods go through multiple delivery cycles.

These real-world examples show the potential and practicality of IoT integration into Malaysia's food and beverage cold-chain process flow. By moving manual inspections to real-time, sensor-based monitoring, companies can reduce product loss, respond immediately to temperature fluctuations, and satisfy food quality regulations. The use of such technologies serves as an important benchmark for guidelines that could be applied to small food and beverage firms in comparable settings.

Benefits of Real-Time Temperature Monitoring

Real-time temperature monitoring has been shown to improve food quality challenges that the cold-chain food industry is currently facing. Real-time monitoring of temperature deviation. Real-time monitoring and tracking in the cold chain logistics sector creates higher levels of efficiency when energy consumption reduction and overall stability in the system are paired with real-time monitoring. An IoT-based real-time monitoring system, including managing energy consumption, is one way to address the constant concern of excessive energy consumption and operational inefficiencies within the cold chain logistics sector (K. Wang & Du, 2025).

Time-temperature indicators (TTIs) are valuable instruments that track the temperature history of food items and provide real-time monitoring of temperatures, which decreases food waste and increases food safety. TTIs create realistic management of the cold chain and cold storage of foods to maintain safety and quality of fresh food items during distribution and transport (Gao et al., 2020). Real-time monitoring can be helpful to determine the remaining shelf life of food products, using some of the advantages of traditional "sell-by-date" labels that do not take into account actual temperature fluctuations.

Unplanned temperature fluctuations can undermine the quality of food based on the quantity of microorganisms that may be present, thus requiring important parameters to be monitored in real time throughout the life cycle of the food product. Therefore, real-time temperature monitoring improves the economic and environmental benefits for cold-chain logistics that can ensure product quality and safety (K. Wang & Du, 2025). Real-time temperature monitoring is also relevant to the cold-chain process flow discussed in the study.

Limitations and Barriers

Real-time temperature monitoring is important for food safety and quality in cold chain operations, but its broad adoption and efficient use are restricted by a number of limitations and obstacles. The limitations and obstacles ultimately impact the accuracy and suitability of nearly all monitoring systems by having a broad impact on technological, operational, and financial factors. Similarly, the limitations and barriers that exist are not merely limited to the Malaysian context but are commonly found in cold chain operations around the world, both in developed and developing contexts.

First, the limitations towards technology and system acceptance. To illustrate, the current systems in Malaysia have limited monitoring parameters that only monitor temperature and humidity but not gas concentrations and luminosity. Temperature and humidity are not the only parameters that are important to food quality. This also leads to incomplete monitoring and risks to perishable goods (Afreen & Bajwa, 2021). Another issue is sensor coverage and placement. With high costs associated with digital sensors, fewer can be employed, and not every product or case can be monitored. This could lead to data gaps caused by the inability to capture temperature excursions (Shou et al., 2023).

Next, due to operational and human factors. Manual data collection is still common, increasing labor demands and the risk of human error. Many food handlers in Malaysia report lacking the necessary tools or training to detect temperature abuse or product damage, limiting the effectiveness of monitoring systems (Wong et al., 2020). There is often a lack of standardized protocols and practices across the industry, leading to inconsistent temperature management and monitoring (Pajić et al., 2024).

To conclude, while real-time temperature monitoring is a vital component in achieving safety and quality in food products within the cold chain, it is a complicated procedure that involves many challenges on technological, operational, and financial fronts. These challenges exist not just in Malaysia, but around the world and for both developed and developing economies. Too many incomplete monitoring aspects, too few sensor installations, manual data collection, and a lack of training overall influence and deter the success of monitoring systems. Addressing these challenges through technology, skilled personnel, and singular industry practices is critical in driving cold chain resilience and reliability across industries globally.

Previous Guidelines

Flow Chart of Pre-Cooling, Processing and Packaging of Origin

The first guidelines were found from Gruyters et al. (2019), which show the flowchart of pre-cooling, processing, and packaging of origin. The figure illustrates the integration of IoT technology in cold-supply chain logistics systems focusing on fresh agricultural products during the early stages of the supply chain.

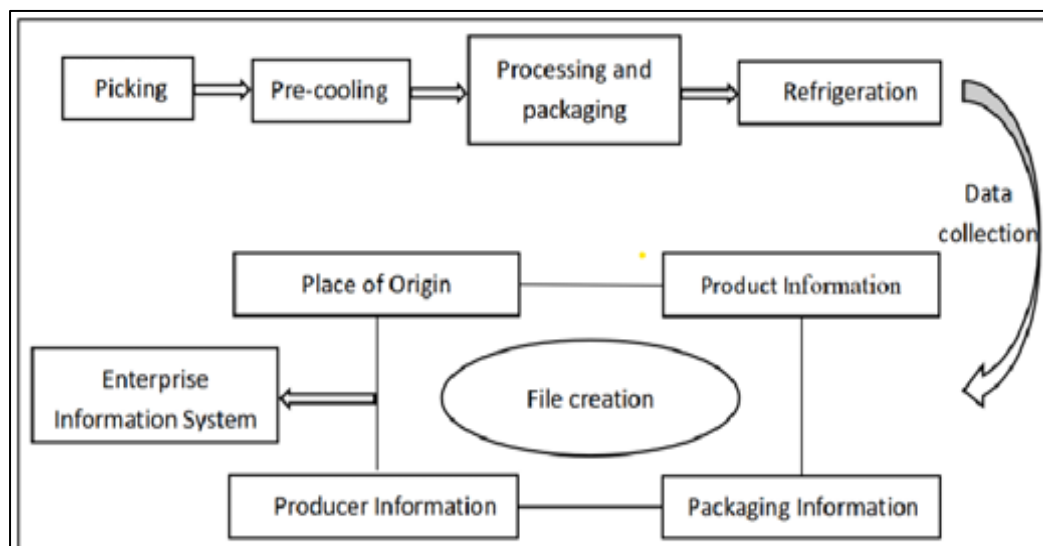


Figure 1 Flow Chart of Pre-Cooling and Processing and Packaging of Origin (Gruyters, Defraeye Et al. 2019)

For the top flow of the flowchart, it shows the physical movement of agricultural products through several stages like picking, pre-cooling, processing and packaging, and refrigeration. The first stage, which is picking, is a process of harvesting crops or slaughtering livestock at the place. It is critical during this stage because it is the moment when temperature control begins to prevent any early spoilage of products. After picking is done, it will continue with the pre-cooling step. This step requires products to be rapidly cooled down to remove the field heat during the harvesting stage. This step is essential to ensure that it slows down microbial growth and extends their shelf-life significantly. During this stage, IoT sensors are used to monitor whether the temperature is suitable for the products and maintained during the process. The most common technology used is vacuum pre-cooling technology. This can quickly evaporate water from the produce under vacuum conditions, which effectively preserves the product freshness and quality of the product. This technology cools the product to the desired temperature quickly, then takes the product from the equipment to be processed, stored, and transported, and finally sold to the buyer. This will make the purchasing process faster and more efficient for the buyer (Gruyters et al., 2019).

Then it will continue to the processing and packaging process. This involves sorting products, grading, and cleaning the produce. After that process has been done, it will then be packaged using appropriate materials such as modified atmosphere packaging. This packaging effectively meets the requirements of packaging for fresh product e-commerce companies (Gruyters et al., 2019). It is the lightest, simplest, and most effectively maintain the original quality of the products. Then, it will continue with the refrigeration stage. During this stage, products will be transferred to cold rooms or any refrigeration units to maintain low temperatures before going to the shipment process. Refrigeration units are commonly monitored in real-time using humidity and temperature IoT sensors to avoid any sudden changes in temperature during storage.

The second part of the flowchart is the data collection process. Various information regarding agricultural products must be collected to ensure that any specific requirement is known to ensure high-quality products. Information such as place of origin, product information, packaging information, and farmer information. All the collected data will then be uploaded to the information systems of the production enterprise in order to able to facilitate product information inquiries. Firstly, the place of origin is information regarding where the

product was grown to improve customer traceability of the products. For product information, it is mostly about variety, maturity of goods, and expected shelf life, which is used for inventory and pricing decisions. For packaging information, it involves the type of packaging material used, packaging time and date, and method of packaging. It is important for food safety audits and quality checks in the future. Lastly, the producer's information. It contains details about the production facility regarding its certification, contact info, and batch number. It is crucial to ensure transparency of products throughout the supply chain process.

Cold-Chain Process of Table Grapes

The second guideline is from Xiao et al. (2015), which provides a process figure regarding a cold chain logistics process specializing in grapes. It is known that the table grapes were transported from Xinjiang to Guangdong province in China, which is around 4300 km for one-way transportation, and takes around 15 days to complete.

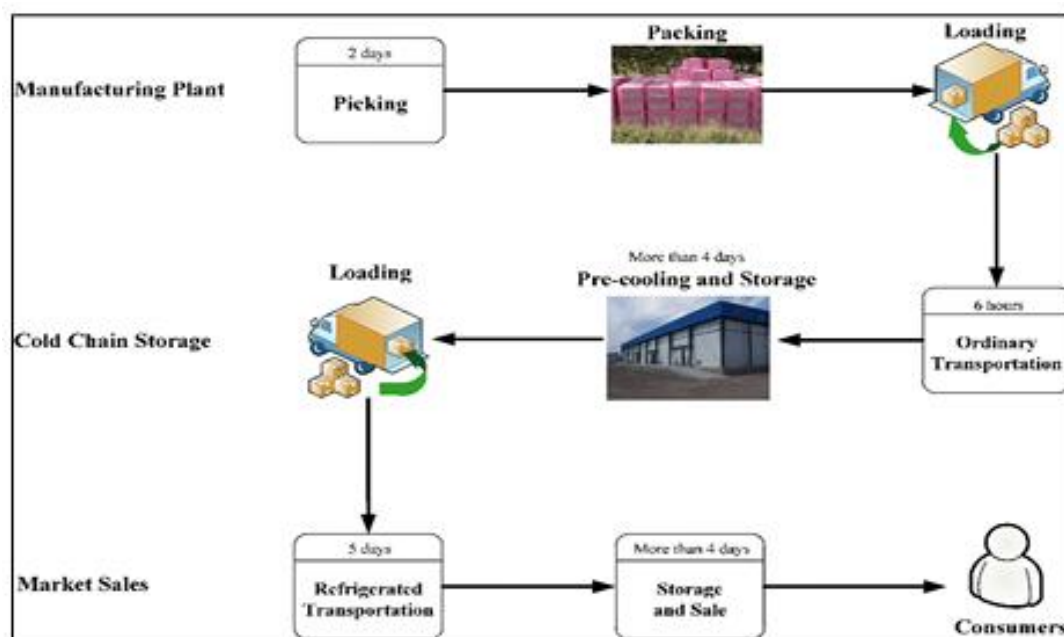


Figure 2 Process of table grapes' cold chain logistics. (Xiao et al., 2015)

The above diagram demonstrates how the logistics process for grapes includes strict processes to ensure both product freshness and product quality. The process begins at the manufacturing plant. At the manufacturing plant, fresh grape clusters ("bunches") are harvested when ripe (usually in the early evening, only on dry weather days, to avoid moisture-related spoilage). Following harvest, each bunch is commercially packed in boxes, in preparation for initial processing. From here, the grapes are transported, in ordinary trucks, to the cold storage facility. This transportation portion is still "non-cold chain"; therefore, the grapes will be subject to temperature and humidity variation, as determined by ambient conditions, so ideally the grapes will be processed upon appropriate arrival, to help eliminate negative effects initiated by this dynamic.

Once the grapes arrive at the cold storage building, they undergo a very important pre-cooling step. This process is important because grapes, along with other fresh produce, still metabolize after harvest. It is critical to cool grapes down to 0°C or below while safely maintaining a relative humidity that is at or above 90%. All this works to cool and reduce the grapes' metabolism, which prolongs freshness. After pre-cooling, the grapes are kept under those conditions for at least three days.

Once the wine grapes are loaded into refrigerator trucks, the cold chain cycle is just beginning. It is important for the cold chain cycle to maintain a steady temperature and humidity, and transporting grapes usually needs to occur within six hours. Our 26 grapes are transported in refrigerated conditions for approximately five days before they reach their destination market. Once they arrive at the destination market, the grapes are unloaded and then placed in storage again for more than four days before getting to the end customer in the market. The

environment of sale may differ in temperature and humidity depending on the location, but this entire cold chain process, before sale, is essential for maintaining the quality of the product, minimizing spoilage, and, ultimately, the quality experience for the end customer.

Packaging Centre Workflow

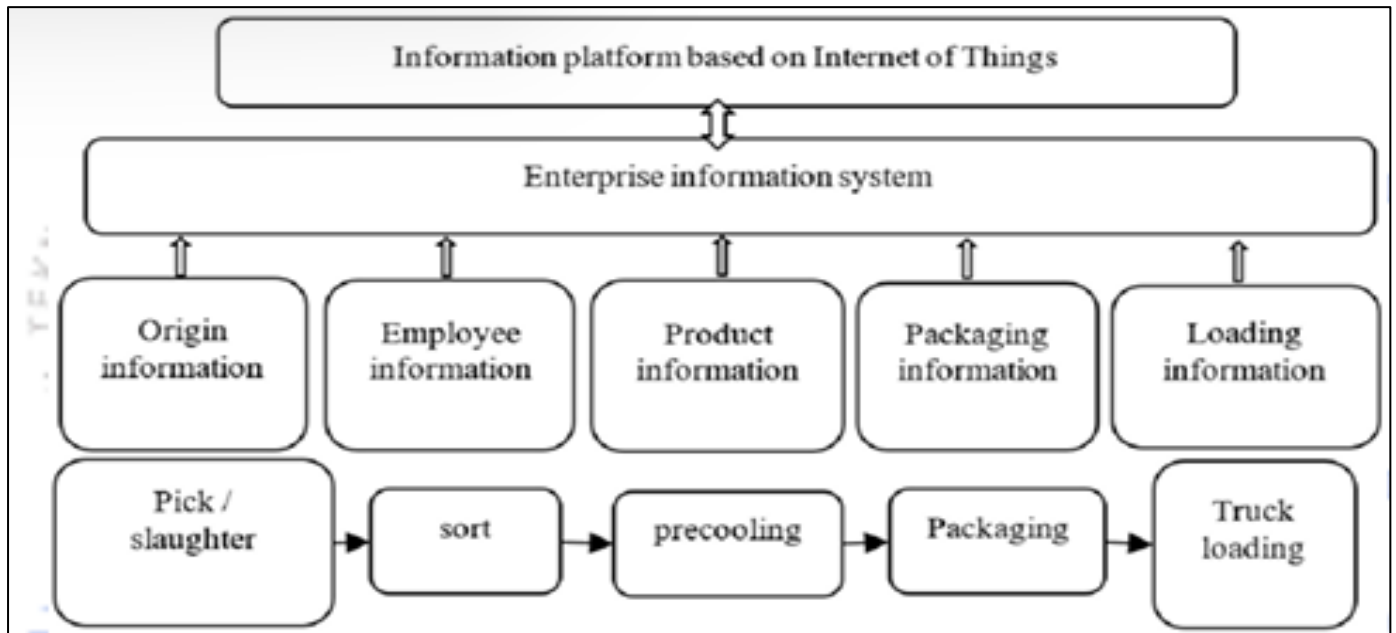


Figure 3 Packaging center workflow (developed by Y. Wang et al. (2024), adapted from Chen et al., 2020)

The third guideline, which is the packaging center workflow for fresh agricultural products, is an important part of the cold chain logistics system and is often improved in effectiveness by the addition of Internet of Things (IoT) technologies. It begins with picking or slaughtering, where the raw agricultural products are being picked up or processed. At this time of origin, information about the produce is collected by location of farm, time of harvest, time of batching, etc and sent to the Enterprise information system (EIS) at the time of picking or slaughtering recognition by descriptors or suggests use of IoT trackers for complete description for traceback to local farm. The second stage is sorting, where the consumer products are sorted based on size and quality.

In this phase, employee data is also documented using RFID tags or biometric systems as part of the IoT platform, which strengthens traceability and accountability if quality issues occur. Then the products go into the precooling stage, an important and sometimes crucial step in the cold chain. As the products are precooling, IoT sensors record the precise temperature, humidity, cooling time, etc., to confirm that the product reaches optimal storage conditions. This real-time collection of data is automatically sent to the EIS system and stored in a cloud-based IoT information platform; the cloud system also immediately alerts stakeholders if cold chain standards are deviated. During the packaging process, using IoT systems, multiple pieces of packaging information are recorded, including materials used, product weight, time of packaging, and shipping label information. Smart packaging technologies, including QR codes or NFC tags, can be added to the units, giving downstream supply chain partners and consumers instant access to product history. Finally, as the trucks are being loaded, IoT logistics systems also capture loading information regarding the vehicle ID, time of loading, and GPS location information as well as the target destination. IoT-integrated logistics systems can also monitor in-transit conditions, ensuring that the cold chain is maintained post-packaging facility.

Within the overall flow of this process, IoT acts as the enabler of real-time data collection, transmission, and monitoring via a central information platform. This connectivity provides the benefit of ensuring that all linkages in the packaging and handling processes follow cold chain requirements, lowers spoilage risks, and increases product safety, transparency, and traceability from the source to their final destination.

Proposed Guidelines

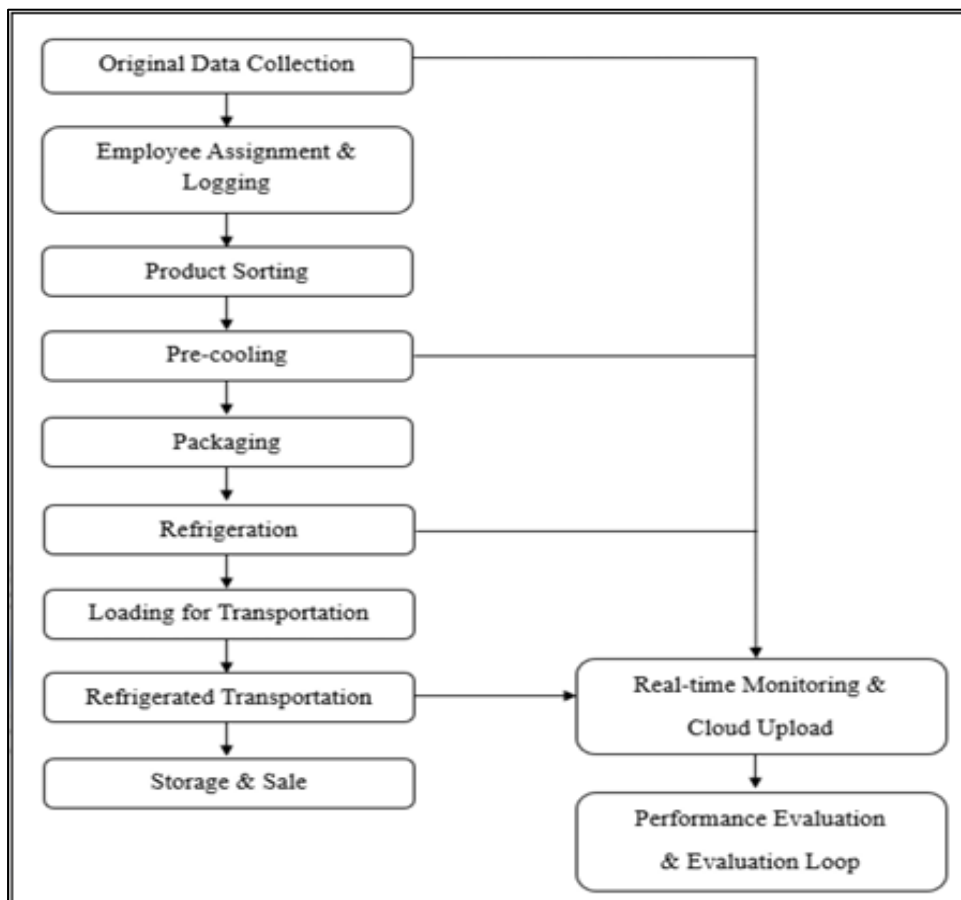


Figure 4 Proposed IoT-Enabled Cold-Chain Process Flow for Enhancing F&B Quality

The theory applied to formulate the guideline is built on both operational practicality and theoretical understanding. The theoretical body invoked here is the Technology–Organization–Environment (TOE) framework theory (Tornatzky & Fleischer, 1990), which recognizes three factors that influence technology adoption: technological capabilities, organisational readiness, and environmental pressures. These three dimensions are critical development components in ordering and designing the guideline, ensuring it is practical, realistic, and relevant to the industry's requirements (Baker, 2012; Oliveira et al., 2011).

The technology dimension is integrated with aspects like real-time monitoring devices, smart packaging, and cloud-based data analytics that support product visibility and understanding the condition of goods/cold-chain assets (Awa et al., 2015). The organizational dimension is embedded with features like workflow logging, employee accountability, and performance reviews that add to productivity and internal process management (Oliveira & Fraga Martins, 2011). The environmental dimension is integrated with traceability, regulatory compliance, and responsiveness, adjusting to customer expectations, which would address product safety and market demands.

Steps begin with the collection of primary data, which includes essential details like the category of product, source, and starting condition, and is methodically collected. It is from this vital information that traceability can be maintained at every stage of the product's lifecycle, providing an accessible and auditable record at any time. Then, venture into the employee assignment and logging step. This step is vital as it ensures that every task can be assigned to an individual, creating not only better visibility for the overall team, but it also makes performance assessment easier --ensuring their teams are working as intended by just looking at who is in charge of each step in the process. The logging step also allows for the detection of potential inefficiencies or room for improvement, creating constant opportunities for streamlining the workflow.

Next, product sorting converts items based on quality or handling factors and identifies and differentiates

items with the essential characteristics: size, colour, ripeness, and weight. In an orderly manner, products can be classified correctly based on their unique characteristics. This sorting process will ease the operations of merchandising and selling products while improving the efficiency of inventory management. The next step is pre-cooling - that is, the process of quickly bringing the temperature of fresh produce and perishables down before processing. Pre-cooling items were an important step in maintaining the quality of the item and the shelf-life of the product. By dropping the temperature quickly, you will reduce the metabolic activity of the produce, assisting with slowing the ripening process and delaying spoilage activity. Keeping the fruit or vegetables fresh helps ensure the best item to the consumer.

Then the products are placed into a packaging step where those products are sealed and labelled accordingly, often called smart packaging, where these packaging processes contain IoT sensors to monitor the condition of products. Smart packaging has advanced the protection of products and their integrity but also allowed producers and producers to have a real-time update on the status of their product throughout the entire supply chain to track product variables like temperature, humidity, exposure to light, and several others. Advanced packaging technologies are critical to protecting the products, especially perishable items, and giving consumers critical information about how products stay safe and fresh for consumers.

The sheath aspect of packaging and advanced cooling and temperature technologies, such as temperature-controlled vehicles and smart refrigerators, can be utilized as further ways to provide evidence of the incident and system reliability once completed with packaging. Once the packaging step is complete, the cooling system will provide the products with the required temperature below the standard serving temperature, arguably very vital for temperature-maintained products like medicines and food items so that they can be put into commerce. It becomes critical without any deviations, because improper temperature conditions can lead to spoilage for most products and further product loss due to unmaintainable cooling conditions for medicines.

The moving phase for transport is a complex process that is carefully controlled and scheduled to minimize delays and ensure that the product will be delivered on time. During the loading stage of transportation, workers follow strict procedures that involve using specialized equipment in the process of product transfer from storage to the transport vehicle, to avoid any damage whatsoever. For this reason, additional logistics software is being implemented to improve scheduling and routing by predicting alternative traffic flows or any potential delays, to ensure that the product is delivered on time.

The sophisticated Internet of Things (IoT) devices placed in the shipping container monitor conditions such as temperature, humidity, and GPS location in real time during refrigerated transport. These devices monitor not only the necessary variables to preserve the quality and safety of temperature-sensitive goods but also employ modern sensing techniques to monitor changes that could also jeopardize a product's integrity. The monitored data is uploaded to a Real-time Monitoring & Cloud Upload and serves as a central point for processing information.

Real-time Monitoring and Cloud Upload can allow stakeholders, such as logistics management, warehouse management, and even the end consumer, to access live data feed from anywhere on the planet, thereby allowing a seamless flow of information and enabling quick and informed decision-making. By utilizing dashboards and alert features, stakeholders can visualize and identify risks and deviations from the planned route or temperature levels and respond before any damage is done.

The final steps are storage and sale, where goods are stored under monitoring conditions and delivered to end users. This step can be important for perishable, just about any change can result in spoilage and, in turn, customer inconvenience and brand damage.

More importantly, all data collected comes to bear in a performance measurement & evaluation loop. A continuous cycle performs analytics on the performance, compliance, and results from each step of the overall supply chain process. It is not the case that this is purely a reactive feedback loop; it plays a proactive function to improve operations over time by creating a cycle of continuous improvement. Companies can alter policies and practices based on real-time operational feedback, while also trialling new storage methods, sales

strategies, or inventory maintenance in the hope of better performance.

DISCUSSION AND CONCLUSION

This paper has given a detailed review of the literature and guidelines relevant to cold chain logistics and the implementation of Internet of Things (IoT) technology in this area. It started with a discussion of valuable frameworks made by academics, including Gruyters et al. (2019), Xiao et al. (2015), and Wang et al. (2020), who all presented important contributions to the idea of managing perishable goods regarding smart packaging, temperature control, and digitization of processes.

The similarities and differences were compared, and the summaries of the three guidelines highlighted certain commonalities, such as the need for data tracking, commitment by employees, and end-to-end monitoring. Using this data, this paper also started the design of a new guideline, which reflects strong data-oriented previous models but was reflective of practical cold chain needs, especially in current technological capabilities.

The custom guideline, which will be further evaluated in a future paper, includes critical items such as data collection, employee responsibility, pre-cooling, packaging, refrigeration, transportation, and performance reporting. Data-driven cold chain management can be real-time, cloud-based, and is fundamental to cold chain commercial practices, allowing constant tracking and actioning before spoilage to the product before it takes place.

Overall, this paper laid the foundations for beginning to implement the proposed cold chain management guideline, which would demonstrate that IoT could lead to better overall efficiency, traceability, and quality of the product throughout the entire supply chain process.

ACKNOWLEDGMENT

The authors acknowledge the support given by Fakulti Pengurusan Teknologi dan Teknousahawanan, Universiti Teknikal Malaysia Melaka, for the financial support and facilities provided in completing this research. The authors would like to thank the Centre of Technopreneurship Development (Cted), UTeM, for their direct and indirect contributions.

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