Chapter 12

IoT and Smart Packaging: A Novel Approach for Managing Food Waste

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A. Introduction

It has long been known that massive losses arise in our agricultural supply chain of rising, cultivating, handling, and delivering food to consumers. Food wastes start mostly on the farm, during production, and proceed through handling and wholesaling. Numerous early phase losses are unavoidable, such as weather, pest infestations, molds, wastages, rodent harm, and stockpiling, handling, and shipping failures.

Food waste is a major challenge in developing countries such as Indonesia. The recycling bins and wastes generated are evidence of these conditions. Office and home premise eateries, large and small streetside food stalls, public get-together gatherings, and celebratory

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events can generate a huge amount of food waste. Food waste is a common sign of pollution to the world's environmental factors, and causes significant financial loss. According to current research, half of food is wasted globally; each year, approximately one-third of all food produced globally—approximately 1.3 billion tons—is lost or wasted (UNEP, 2020). This figure is expected to rise even further in the future, which is a concern.

The COVID-19 pandemic has compelled many restaurants, coffee shops, bars, and other food warehouses to shift from on-site selling to e-commerce with non-contact delivery or roadside pick-up. Many food production lines, particularly meat production plants, were forced to close given the high rates of infection caused by close working distances and long hours of work. For instance, over a thousand cases of COVID-19 were confirmed from a meat factory in northwest Germany in the summer of 2020 (Deutsche Welle, 2020). As a result of the disruption, there has been an increase in food waste and economic losses. According to Andre Laperriere, Executive Director of Global Open Data for Agriculture and Nutrition (GODAN), the pandemic has increased food waste in developed countries by 30% to 40%. Similarly, when supply chains fail and restaurants and other infrastructures (schools, universities, and the hotel industry) are forced to close, several farmers are left with massive amounts of unsellable harvests (fruits and vegetables), resulting in economic losses, high waste (disposal dairy, meat, and fresh produce), and a decrease in sustainable development (Kawamura, 2020). These problems highlight the importance of strategy and systemic changes that encourage food supply diversion when the supply chain is disrupted.

Amidst large increases in environmental consciousness in the world's developing countries in recent years, there seems to be little real consideration given to food waste as an environmental problem, nor any endeavor to secure it within a broader sustainability perspective. Indonesia lost annually 115–184 kilograms of food per capita on average, which was concluded by the National Development Planning Agency (BAPPENAS) in partnership with the World Resources Institute and the management advisory firm Waste for Change. According to their study, yearly food waste causes economic losses of IDR 213–551 trillion, equivalent to 4–5% of Indonesia's GDP. In the same period, this generation also produces greenhouse gases (GHG) emissions of 1,702.9 megatons CO^2, equivalent to 7.29% of Indonesia's average annual GHG emissions. The impact of food waste at the retail and consumer levels adds to the global footprint of food emissions. If food waste were a nation, it would be world's third-largest producer of greenhouse gases, according to Flanagan et al. (2018). The total energy loss from food waste is equivalent to the food portion of 61–125 million people per year. The data also show that grains account for the majority of food loss and waste, while vegetables are the least efficiently processed, accounting for 62.8% of Indonesia's total domestic supply of vegetables (BAPPENAS, 2021).

Consumers gave more than 30 causes for wasting food, the most frequent being cooking food excessively, not making proper food plans, purchasing too much, shifting objectives, not eating meals at the proper time, and not being interested in the meals cooked. Consumer uncertainty over date coding was also commonly discussed in the WRAP (Waste and Resources Action Programme) studies, with one in five consumer robustly dismissing meals near to its 'best before' date, even though it was still good to eat. Consumers have failed to keep up with food, such as what it is, where it comes from, and how it has been managed to produce. Consumers believe that food is cheap and readily available, so they could sometimes make a strong disconnect, allowing them to throw uneaten food apart while claiming that they do not waste food (WRAP, 2009). Since most consumers are in neglect regarding food waste and are unaware of its ecological consequences, they have the opportunity to educate themselves to improve the situations, for instance by generating awareness about the environmental impact of food packaging, creating an environmental-friendly food packaging system, and providing the food waste solution through the Internet of Things (IoT).

B. Food Waste and Food Packaging

The primary function of packaging is to protect the goods from the harmful effects of exposure and use in the external environment. Furthermore, packaging can be an important promotional platform to communicate with customers. It emerges in a number of various forms and, as a user interface, offers consumers simplicity and efficiency of use. Product packaging has four primary functions: protection, communication, convenience, and containment. For instance, packaging used in food products typically functions as follows:

a. To keep the product from leakage or breaking and safe from contamination.
b. To convey critical knowledge about food products and their nutrient content, as well as to give food preparation directions.
c. To make life easier for customers, such as allowing them to heat it in the microwave.
d. To assist in the facilitation of transportation and handling.

Conventional packaging, however, is no longer adequate due to high consumer expectations, increasing product diversity, and, most lately, national and international development to promote a circular economy and reduce the carbon footprint of consumer products. To meet the diverse needs of consumers, innovative and smart packaging with increased functionality is undoubtedly required. Some examples are worth trying, such as offering packaged foods with fewer preservatives, creating products that meet higher regulatory standards, and designing package system that enables traceability from inception to delivery, representing protection against lawsuits. Furthermore, smart packaging can facilitate market expansion in the global context, aid in implementing more strict domestic and international food safety standards, and even safeguard against potential food bioterrorism threats.

Smart Food Packaging

Smart packaging is a concept that has emerged in the literature over the last two decades and is frequently used. It refers to the packaging systems used for perishable goods such as food, beverages, pharmaceuticals, cosmetics, and etc. According to Vanderroost et al. (2014), smart packaging can be refers to intelligent and active. Smart packaging provides a complete packaging solution that, on the one hand, monitors and responds to changes in the product or the environment.

In smart packaging, chemical sensors or biosensors control the quality and safety of food from the producer to the consumer. Smart packaging, like the other innovations discussed thus far, employs a variety of sensors to control food quality and safety, including identifying and evaluating freshness, bacteria, spillages, carbon dioxide, oxygen, total acidity, time, and temperature.

A smart packaging platform's specific functionality varies and depends on the product being packaged, such as food, beverage, medicine, or many health and household supplies. Consequently, the precise circumstances for monitoring, delivering, or adjusting would differ. Smart packaging allows producers, resellers, or consumers to follow a product's life cycle and evaluate it. It also helps mitigate the environmental impact within or outside the packaging by providing real-time information to the producer, reseller, or consumer about the product's status.

Application of Smart Packaging

Smart packaging innovation has a variety of uses, from food quality and drug consumption monitoring to postal mailing tracking via embedded security labels. The possibility is viewed as a value-added benefit from the consumer's perspective. In today's world, where people are always connected to the internet, a new approach to monitoring and controlling purchased items via linked apps has emerged as a significant commercial opportunity for businesses looking to increase customer satisfaction. Smart packaging can also reveal supply chain waste and inefficiency, save expenses, improve product quality, and increase profitability.

The challenge in implementing smart packaging is that food waste can be generated at various stages in the food supply chain. Once food reaches the supply chain, packaging becomes vital in maintaining its security, freshness, and high quality. Developing integrated packaging sensors can help amidst the handling of recovered packaging and thus hopefully reduce food waste. Such sensors can retain data such as packaging material, food expiry date, oxygen concentration, temperature, and pH level. Through the new technology known as Internet of Things, this data may be shared with food producers, distributors, and even packaging recycling companies.

Food waste can occur at any point along the food supply chain. Consumer behavior, for example, has contributed significantly to the increased amount of food waste at the end-of-life stage. Contamination and damage due to inadequate safety procedures, overstocking items in shops, incorrect tagging, and missing product details are just a few of the main causes of food waste in the supply chain. Perishable bakery and culinary products account for a significant portion of food waste, with repercussions throughout the supply chain (Mena et al., 2011). The major cause of this issue is frequently an excess excessive supply that surpasses demand, a shorter product shelf life, or inadequate storage conditions. It is also worth noting that the root causes of food loss and waste differ between developed and undeveloping countries. For instance, in developing countries, roughly 40% of food is lost during the production phase, while in developed countries, 40% of food waste is generated throughout the transportation, selling, and consuming stages (Wunderlich & Martinez, 2018). Attention has been drawn to the increasingly alarming rates of food loss and waste (FLW. Food waste also connects with public health issues regarding food security, safety, and nutrition, negatively influencing socioeconomic development. Food waste, for example, can result in higher food prices, reduced incomes, and increased poverty. Furthermore, wasteful activities can harm the environment, including land, freshwater, oceans, forests, and wildlife.

- The Impact of Smart Packaging on Food Waste
  The term "smart packaging" is frequently used interchangeably or incorrectly when discussing packaging systems. The term "smart packaging" refers to both intelligent and active packaging. Smart packaging can detect external and internal shifts in a product and respond (actively) by interacting with an external interface (electric or optical). The main goal of smart packaging development is to improve the shelf life of the product and its health, transfer factual information to consumers, optimize safety, and enhance product traceability as it moves through the supply chain. The primary alternative to traditional packaging is active packaging, which aims to encourage and maintain high quality while extending food product freshness. To accomplish this, various components can be combined to form a scheme capable of releasing and absorbing materials from and into food products, thereby reducing waste. Smart packaging, on the other hand, is used primarily to monitor and check the status of packaged foods, as well as to collect and provide data on product conditions during storage and transportation procedures. As a result, a smart packaging system employs some common components, such as gas detectors, freshness and maturation indicators, temperature-time indicators (TTI), and radio frequency identification (RFID) devices.

Technological advancement in food safety issues is one of the most important steps in preventing food waste. Examples include energy-efficient and temperature-controlled storage solutions, new packing material and design features, and sophisticated tracking systems. Improved and innovative techniques, in particularly active packaging and smart packaging, have proven to be valuable tools for food waste reduction while also ensuring food safety and fulfilling customer demands. Even though devices for smart packaging, such as electrochemical sensors, E-Tongues, and E-Noses, have advanced significantly, today's devices are typically complicated and costly, and are not even prepared to be integrated with actual packaging. The statements "best used before" and "sold by" or "used by" have become the norm in today's food industry, but they struggle to provide data on the status of the food within the packet, so "dynamic shelf-life systems" must be initiated for easier understanding. In this regard, the environmental sustainability of food packaging is a concern; thus, research on mapping the ecologic performance evaluation of packaging is critical to deliver guidelines to packaging design experts.

Advanced inventions are being developed urgently for food and nutrition security. The use of modern technology in smart packaging has appeared. It has lately been accepted by the food and pharmaceutical applications as a tool to extend shelf life of food. It can be used for manufacturing operations, reducing food waste, eliminating additives, and, most importantly, offering better quality and availability to ensure safety and consumer satisfaction. Developing advanced food packaging systems, specifically targeting chemical and biological markers in food remains a significant challenge. The selection of a target marker is influenced by prior knowledge of the specific microbial agent and its presence under diverse circumstances in different food products, including the transmission of reactants generated during the spoilage stage.

Food contamination is a delicate system that can be triggered by a variety of physical, chemical, or enzymatic processes, as well as pathogenic activity. pH changes, as well as the presence of toxic materials, toxic fumes, gases, and mucus, may be caused by microbial population and metabolic activity. Chemical reactions such as oxidation, irradiation, and lipolysis can generate unwanted flavors and side effects. In addition to intrinsic parameters, external variables (temperature, pH, and humidity) can influence food waste chemically, physically, and biologically (physicochemical and structural). Food spoilage Food spoilage, ripeness, rancidity, microwave maturity and RFID are just a few technologies available to help reduce food spoilage.

Smart RFID tags are intended to assess the quality of food products using a combination of sensing elements. These RFID tags could identify changes in food properties, such as food volatiles, permeability, pH, viscosity, dielectric constant and gases using chemical equipment such as responsive coatings, optical labels, litmus paper, and pH or conductivity electrodes. Some examples include applying various food volatile responsive films to RF constructions and sensing the change in response through color changes of certain dyes caused by volatiles from food or due to changes in food pH for colorimetric sensing, as well as checking variants in the dielectric constant of food due to spoilage (Potyrailo et al., 2014). As a byproduct of degradation, food naturally emits volatile components. Byproducts of microbial activity that can be used as predictors of food contamination include trimethylamine, ammonia, dimethylamine, carbon, sulfate substances, histamine, and ethanol. Solid-phase microextraction was combined with gas chromatography-mass spectrometry, UV-VIS spectroscopy, and near-infrared spectroscopy to detect and quantify volatile compounds in foods. Nonetheless, these tools are expensive, complicated, and time-consuming, especially when compared to smart sensor-enabled RFID, a cost-effective, unobtrusive, and user-friendly food packaging technique. Furthermore, because it contains identifiers that can interact with food ingredients and metabolic products in extrinsic environmental factors, this packaging system can potentially be a powerful tool for reducing food waste.

According to a Boston Consulting Group (BCG) report, there are already slow actions to reduce food waste throughout the supply chain due to a lack of technology, effort, regulatory frameworks, and collaboration across the value chain. Infrastructure upgrades and supply chain efficiency are only estimated to save US$ 270 billion (in value) or US$ 1.5 trillion by 2050. Smart packaging systems can help with this by reduce food waste and enable more sustainable supply chain management. For example, data carriers will aid in linking information in the supply chain to improve process efficiency and ensure traceability, automation, theft prevention, or counterfeit protection. RFID will help with inventory control and traceability, improving food quality and safety throughout the logistics system. TTI will also aid in precise temperature characteristics or cold storage tracking throughout the supply chain. As a result, smart packaging will not only drastically reduce waste and loss by improving supply chain distribution efficiency and accurately detecting food spoilage, but it will also address health and safety concerns. Moreover, not only can smart packaging reduce the period and content costs associated with analyzing packaged foods, but it will also save cost due to its capability to eliminate food waste. The proposed bioactive smart packaging is expected to become a future trend, creating new opportunities, increasing market demand, and gaining acceptance from more food producers.

Continuous improvement in food waste data collection is expected to aid in the decision-making and promotion of this packaging design. Furthermore, modern manufacturing innovations are designed to decrease factory production costs and improve the integration of smart devices into today's packaging lines. Additional research into the issue of safety and feasibility, as well as the prospect of inclusion in various applications, is required. Finally, customer must be well educated about these innovative packaging systems, including their costs and benefits, as well as their willingness to shop.

C. Internet of Things-Based Food Waste Management

The term "Internet of Things" is used as a catch-all phrase to refer to various aspects of the physical extension of the internet and the web via the massive implementation of spatially distributed equipment with integrated recognition, detection, and/or actuation functionality. The Internet of Things envisions a world where physical and digital objects can be connected using suitable information communication technologies, allowing for the development of innovative class applications.

The Internet of Things (IoT) is an exchange of information in which everyday items use technology to electronically connect and engage with one another and their users for the advantage of the users (Deokar et al., 2018). The Internet of Things (IoT) comprises physical components with digital counterparts and virtual representations. In this way, things gain context awareness and can sense, connect, communicate, and exchange data, information, and knowledge. The use of virtual elements as a central planning, interoperation, and coordination tool has the potential to transform food supply chains.

IoT in supply chain management is very appealing because ineffective supply chain processes cannot respond appropriately to a constantly changing situation caused by globalized society (Ben-Daya et al., 2019). Efficiency, which is highly important in the Food Supply Chain (FSC), can help reduce and prevent resources-food waste.

Smart packaging with sensors could alert users to the use of IoT technology while also reducing food waste. Smart packaging technologies can detect the absence or presence of glucose, ethanol, volatile gases such as ammonia in fish, pathogenic substance, color degeneration, and other contaminants. Packaging labels with a variety various time-temperature indicators (TTI) have been developed. However, the greatest barrier to this technology implementation, is a lack of technical understanding of smart packaging and IoT, and the cost of implementation. Intelligent fridges have been developed alongside smart packaging, smart mobile devices, and the associated applications (Vanderroost et al., 2014), so this is now regarded as a in greater concern.

Organizational food waste management is difficult for anyone in the food service industry. This problem could be well managed using the Internet of Things (IoT) This innovation has progressed from the stage of scientists to the phase of implementation, making it a critical application technology with the potential to deliver smart services.

As the Internet of Things (IoT) and devices have grown in popularity, security has become increasingly important. As more end items or organizations are connected to the Internet of Things (IoT), more generated data must be transmitted over the server. The information is then analyzed and evaluated to be effectively used. Because of the resource constraints of Internet of Things (IoT) tools, different security has been highlighted for various end tools. The Internet of Things (IoT) is gaining traction in the focused intelligent transport system, in which the vehicles connect smartly with one another. When the vehicles connect smartly, there is a much lower risk of a fatal collision. The Internet of Things (IoT) assigns a different IP address to each device, it is very difficult to hack.

Physical entities in an IoT environment are intelligent items that have the following characteristics:

1. Possess a physical embodiment as well as a set of physical characteristics (e.g., size, shape).
2. Use a basic communication skills, including the opportunity to discover, recognize, and respond to new messages.
3. Have a unique identifier associated with at least one name (human-readable description) and at least one address (machine-readable number or string).
4. Device can detect observed processes (for example, temperature and humidity) or trigger actions affecting physical reality (actuators).

Since smart technologies generate a large amount of data, data capture is essential. Data collecting hardware with capability to input and gathering data is a critical component of an IotT device. The following are some notable examples (Lehmann et al., 2012):

a. Data collection during the “food cycle,” which includes agricultural production, post-harvest storage and handling, food manufacturing, and utilization. This information can be gathered using sensor networks, providing detailed information about processing measurements such as relative humidity, temperature, fertilizer and pesticide usage, farm machine driving lanes, and etc.

b. Capturing transport data, such as position and ambient information from inside and outside the truck, allowing logistics management to evaluate the current situation.
c. Collecting data of product quality indicators such as oxygen, humidity, nitrogen content, or ethylene content in the air around a product as an indicator of perishing fruits and vegetables, which is relevant in storage facilities and during transportation, as well as with users and their perception of food product quality class.
d. Capturing data from a product's packaging (for example, the manufacturer's name) to help with cloud retrieval.

To realize IoT implementation, network access infrastructure must be well-designed. The developed IoT applications would also share connectivity, network components, and a common service platform. These applications are classified into three categories:

Table 12.1 Realization Process of IoT Implementation

Collection	• Processes for observing the real world, collecting actual tangible data on food and the environment, and recreating a common perception of it.
Transmission	• The transmission phase includes mechanisms for delivering recorded data to applications and external servers. As a result, this phase require techniques for connecting to the network through gateways and various techniques (e.g., wired, wireless, satellite), addressing, and routing.
Management and Application	• The managerial and application stage is concerned with analyzing and processing information flows, transmitting data to a DLSP model based on the kinetic Arrhenius model because it is temperature dependent, providing feedback to control applications, and alerting users to potential hazards (short period of time in which food product must be used).

Source: Ostojic et al. (2017)

The first step in IoT implementation is to collect data about the physical environment in which the food product is currently stored (e.g., temperature, humidity) or about objects (e.g., identity of crop, meat, etc.). Data gathering is achieved from the use of multiple sensor systems attached to sensors, cameras, and Global Positioning System (Global Positioning System) terminals, while data collection is normally accomplished through quick connectivity, which may be conducted using open source basic solutions (e.g., ZigBee, Bluetooth) or proprietary solutions (e.g., Z-Wave).

Effective food waste management based on Internet of Things framework not just bring valuable information on the condition of food products at each stage of its life, but also predicts their shelf life. As a result, each participant in the life cycle can forecast the remaining shelf life in the time frame that is important to them. As a result, the consumer can decide whether to stick with the current strategy or modify it to reduce food waste. For instance, if a truck breaks down during the delivery process and the temperature rises above a predetermined threshold, the supplier can recognize shelf life and decide whether to continue with the strategy and make deliveries to department stores or bring it back it to the manufacturer.

D. Summary and Conclusion

This chapter explored the influence of application domains like smart packaging and larger IoT development in reducing food waste. These platforms enable the extension of storage and the transition of duration and product life communication from static coding systems to more real-time applications, albeit at a cost. It could be achieved using effective packaging solutions or IoT systems in smart-enabled packaging technologies. While intelligent applications have the potential to reduce end-user food waste, as discussed in this chapter, there are some drawbacks to consider, such as privacy protection or the threat of hacking, as well as aspects about if the possibility of a knowledgeable entity will influence current behavior in the household, when buying or planning consumption of food.

Packaging has a significant strong involvement in treating food waste, both in terms of delivering food to consumers and providing consumers with better methods of handling their food stock, going resulting in less waste. Food packaging should be reduced in the quest for a less wasteful society, but this can only go so far before having a negative impact. Lighter packaging may be preferable, but only if it results in greater product loss elsewhere. There is a contentious discussion about introducing more packaging if it helps consumers reduce food waste by a more significant factor in the home. The battle to reduce food and packaging waste has evolved beyond simple considerations intended to reduce the immediate weight of packaging.

The packaging alone would not fix the food waste problem. Food-saving packaging efforts indicated in previous sections should certainly help, but consumer awareness and changes in consumer behavior will be the most significant considerations in resolving the problem. Packaging is vital because it communicates how we view our food products to consumers. If food is cheaply packaged, frequently produced in mass amount, and poorly secured, it sends a clear message to the consumer that this is a product with little intrinsic value and can thus be discarded without concern.

Food waste can occur at any point in the food chain, which includes agricultural production, post-harvest handling and storage, manufacturing, delivery, utilization, and disposal. An IoT system can be used to mitigate the severity of this occurrence. This chapter describes an IoT system that predicts interactive shelf life using the kinetic Arrhenius model. One limitation of this model is that shelf life determination is only accurate for the relevant product structure, packaging, and handling condition variety.

However, inside this novel frame of mind, it is feasible to reorient the packaging industry as a strong pro-environmental force with significant sustainability influence and power of product protection and aiding in the prevention of waste. In this worldview, numerous opportunities for true packaging advancement can be coupled with IoT technology, some of which have already been mentioned and recommended here, that are coherent with a long-term sustainable society.

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