EPC Sensor Network-based Product and Process Traceability System in the Food Supply Chain

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Abstract

Concerns about food safety continue to rise and under this situation, governments of some countries have reinforced their regulations more strictly for food safety. In order to prevent food safety incidents or, at least to minimize the impact, the preparedness is very important. As a consequence of this, traceability system has become an essential tool for food safety. Recently, it requires more prevention-based food safety control system. One of the most generally used systems for food safety control is Hazard Analysis and Critical Control Point (HACCP). Both traceability and HACCP systems can be integrated through Electronic Product Code (EPC) Sensor Network technologies which have four value propositions. In this paper, we will introduce the concept of product and process traceability system (P2TS) through the integration of three systems to improve food safety management. The final aim is to find out the added values of the P2TS.

Keywords:

Traceability, RFID, EPC Sensor Network, HACCP

Introduction

After a number of food crises, such as BSE, food and mouth disease, bird flu and, dioxin crisis and so on, concerns about food safety have increased in the last decade, since those food crises have had a heavy impact on food industry. One of the most important impacts is that the food crisis drop food sales dramatically affecting not only the consumer's physical health [1]. As a consequence, consumer confidence also can be dropped [2]. Thus, this restoration of consumer confidence is a critical issue in the food industry [3]. In many sector throughout the world, some food safety related regulations have been established at government level. In December 2004, the US food and Drug Administration (FDA) required every participant in the supply chain to keep detailed information of all foodstuffs [4]. On 1st January 2005, European Union (EU) set more strict traceability requirements in the food industry, which can be referred to The EU Regulation 178/2002(2001/95/EC), which also required both producers and retailers to keep detailed information about all food products as they move through the supply chain [5][6]. Japan also imposed a duty to beef industry to introduce traceability system from December, 2004. Among various food safety management methods, traceability will become the imperative concept for a successful solution. And Radio Frequency Identification (RFID) technology is emerging as great opportunities for effective and efficient traceability system design [7].

In this study, we suggest RFID and EPC Sensor Network based traceability system concept for food safety management. Our objective is to outline the traceability architecture that can cover whole food supply chain, while deriving added value of the traceability system from the supply chain management perspective.

Food safety management

The global importance of food safety has not been fully appreciated till now. However, food safety is receiving increasing attention in these days due to several reasons such as, demographic changes, environmental hazards, changing social and behavioral factors and, scientific and technological progress [8]. In accordance with this, several laws and regulations have been established. One of them is recall system. A recall system must stop any further distribution and sales of the unsafe food stuffs as soon as possible and effectively retrieve the unsafe food. With this preventive regulatory, Product Liability is the after the fact regulatory to protect consumers from faulty products.

Another food safety related regulation is ISO 9001-2000 which is the world-wide quality assurance standard. ISO 9001-2000 is the complementary system for traceability including extensive product supply chain from origin (farm) to whole distribution. Goof Agricultural Practice (GAP) is formally recognized in the international regulatory framework and associated codes to practice to minimize or prevent the contamination of food [9]. GAP is an effective system that comprehensively manage agricultural chemical, heavy metals and, microorganisms from cultivation stage of product through harvest, processing, storing to distribution. GAP includes a narrow sense of traceability and can strengthen the traceability system. However, solutions are often reactive, rather than proactive. The preparedness is critical and if this preparedness can prevent the outbreak itself, it will be quickly adopted by many food industries in the world. In this study, we are focusing on the most popular food safety management systems; Hazard Analysis Critical Control Point (HACCP) and Product Traceability System (PTS).

HACCP

In food safety control perspective, HACCP which is the international reference system for food safety management is the most generally used system [10]. According to National Livestock Research Institute Korea, HACCP is the network system for production and supply of food safe and hygienic which made from control (removal) all the hazard factors that would have influence on human being through the stages of production, transfer, slaughter (1st processing), manufacture (2nd processing), circulation for animal (food) production from farm to consumer [11]. HACCP is made of 2 main parts;

- ✓ *Hazard Analysis (HA)*: Identify and analysis hazards.
- ✓ *Critical Control Point (CCP)*: Managing the critical point of the hazards that could have big impact on food safety (on human being). Critical control point is any point of hazard factors that have potential of negative impact on food product safety.

And it has seven basic principles as shown in table 1, which are used throughout the world [12].

Table 1 - The principle of HACCP (Source: Kirby, 1994)

Principle	Subject	Action
1	Hazard analysis	Construct a flow chart of the process stages. Identify and list all potential hazards.
2	Identification of critical control points	Identify CCPs using a decision tree. Specify the systems of control.
3	Establishing critical limits	Target values and critical limits must be set for each CCP.
4	Monitoring	Continual or regular registering at each CCP to verify maintenance of control
5	Correction	Establish protocols for: (i) when CCPs are moving towards loss of control; and (ii) when CCPs are out of control.
6	Verification	Establish systems to confirm the correct functioning of HACCP.
7	Documentation	Establish documentation for all of the procedures and records necessary for the implementation and operation of the above procedures.

HACCP is based on being proactive rather than reactive through a scientific analysis of risk in the supply chain, which means the most suitable risk-based prevention-focused system. By using HACCP system, it can be done more easily for related monitoring institutions to control and monitor more efficiently [13]. However, HACCP has several limitations in its implementation. In the main, it is very demanding to establish HACCP at the farm level due to the lack of financial support and infrastructures [14]. In addition to this, there are still many functions in the manual HACCP performance system, which means there could be possibility of error from manual [15]. In addition, HACCP itself can become very complex due to a lack of internal knowledge of microbiological and toxicological issues.[2] Although the problems in operating HACCP may depend on countries and industries applied, a lack of people, the neglect of duty of person in charge and time to check/manage HACCP and, a lack of financial support including equipment and facilities are mentioned as key obstacles, especially in Korea [16][17].

Product Traceability System (PTS)

The Concept of Traceability System

The definition of traceability is various. According to ISO, traceability is defined as "the ability to trace the history, application or location of an entity by means of recorded information" [18]. In the food industry, traceability is defined by EU as "the ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution [19].

Product traceability can be distinguished in two ways based on the direction to which information is recalled; i) Backward traceability and ii) Forward traceability [7].

- ✓ *Backward traceability (Tracing)*: the ability to find origin and characteristics of a product from one or several given criteria through the whole supply chain.
- ✓ *Forward traceability (Tracking)*: the ability to find the locality of products from one or several given criteria through the whole supply chain.

Traceability system can be distinguished by several perspectives as referred to table2 [20][21].

Table 2 Types of Traceability

Criterion	Types	Description
Business scope	Chain traceability	Traceability through the whole, or part of supply chain
	Internal traceability	Traceability in one of the steps in the chain
Supported functions	Logistics traceability	Traceability which follows only the physical movement of the product and threats food as commodity
	Qualitative traceability	Traceability which associates additional information relating to product quality and consumers safety

In food industry, traceability has broad meaning because food is a complex product and traceability system has a number of different objectives [22]. Golan et al indicated motivations and objectives for private-sector and public sector [23].

Motivations of Private sector are;

- ✓ To facilitate trace-back for food safety and quality
- ✓ To differentiate and market foods with subtle or undetectable quality attributes
- ✓ To improve supply –side management

Motivations of Public sector are;

- ✓ To facilitate and monitor trace-back to enhance food safety
- ✓ To address consumer information and knowledge about food safety and quality
- ✓ To protect consumers from fraud and producers from unfair competition

While the objectives of traceability in the private sector are to assure buyers of the existence of quality attributes including achieving motivations, those in the public sector are to ensure that recordkeeping is sufficient for trace-back, with the aims of mitigating foodborne public health problems including achieving motivations. Through these, we can say the reliability and effectiveness of the food traceability system depends on the degree of accuracy of recorded information. In addition to this, the efficiency of a traceability system depends on the ability to collect the information related to safety and quality [21].

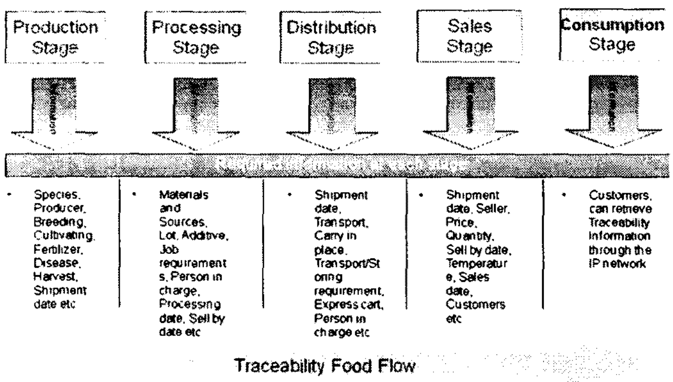

Figure 1 Food Traceability System

Limitation of Traceability for Food Safety Management

Traceability system is one of key components for food safety management. However, we need to note that traceability does not improve product safety, neither its quality. It means that traceability itself does not change the safety and quality of a food product [21][24]. The initiative role is to assure consumers' health and safety by enabling to recall hazard products rapidly in case of food crises. The other side, according to Moe, traceability is an essential subsystem of quality management [20]. Thus, in order to get full benefits of traceability system, we should integrate traceability and quality assurances.

EPC Sensor Network

Introduction to EPC sensor network

RFID system is in the limelight from many academicians as well as practitioners these days. RFID tags can be used to track the movement of food product from the "stable to the table" and the more tightly the food retailers can integrate their supply chain the less likelihood of errors. The ability of RFID to trace and follow food, feed, food producing animal or ingredients through all stages of production and distribution allow food retailers to comply with increasingly strict international regulatory requirements mentioned above [25]. EPCglobal initiated EPC as the next generation of product identification and has started defining standards for an EPC network to support the sharing of unique product identification information among partners in supply chain [26]. EPC sensor network is the unified and integrated framework of RFID and sensor network with aims of supporting RFID class structure from 1 to 5. It covers whole architecture framework including EPC, ID system, EPC middleware, Information Service and discovery services and it can be distinguished itself with established architectures with universal open networked architecture while it is compatible with current architecture framework [27]. This architecture is designed on the top of current EPC architecture framework so that it can support most of current usages without breaking any interoperability of diversified RFID tags. All sensor data has at least one object to combine and information can be stored in remote infrastructure network and communicate to other sensor node with ad hoc technology. EPC sensor network can store EPC information such as object information, location, history tracking, the object state history and, other sensor data. The architecture of EPC sensor network is described in figure 2.

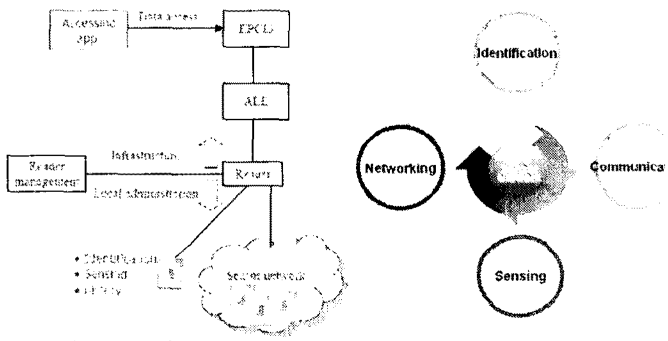

Figure 2 The Architecture of EPC sensor network

EPC sensor network has four properties;

- ✓ Identification: RFID
- ✓ Networking: EPCglobal Network
- ✓ Communication: Ad-hoc and multi-hop technologies
- ✓ Sensing: Sensor nodes

These four properties become value for EPC sensor network and make sensor-based application services in various areas.

Why EPC Sensor Network

From the RFID point of view, EPC sensor network is a necessity in order to support current RFID tags because current EPCglobal architecture supports only RFID class 1 or 2 in five classes. EPC sensor network architecture can support more than current RFID tags.

In case of wireless sensor network point of view, traditional approach is disconnected sensor network.

Wireless sensor network is dedicated application, local scale, never-compatibility with others and, lack of standards. EPC sensor network is internet scale sensor network, which means interoperability, creating more value from network of sensor network. In order to provide universal access to the framework elements, EPC sensor network can use the already established de-facto standard, EPC network.

Product and Process Traceability System

PTS is required to be bundled with quality assurances in order to draw more values of traceability system. One of the most popular and strong quality assurances in food industry is the HACCP system.

These two food safety management systems can be integrated through EPC sensor network to make food safety management more effective and efficient.

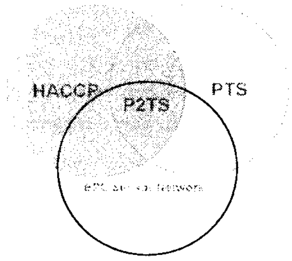

Figure 3 The Concept of P2TS

The original objective of PTS is to assure consumers health and safety by enabling rapid recall and withdrawal of hazard products after incident occurs. From the traceability data management perspective, the data can be split in two parts; static and dynamic [21].

- ✓ *Static data*: product features that can not change, such as retirement or catch date, country of origin, expire date, size, and so on.
- ✓ *Dynamic data*: product features that change over time while product is changing its ownership as moving along the supply chain, such as lot or batch number, order ID, dispatch data, taste, content of chemical components, any transformation data that have effect on the product's nature, and so on.

We note that the dynamic data includes safety and quality related information, which is much more important for food safety management. In P2TS, the information that is currently collected by existing PTS, but also those dynamic data can be collected automatically and continuously at each critical control point by using EPC sensor network technologies. An example of collecting data in meat processing procedure in the concept of P2TS is described in figure 4. In P2TS, this dynamic data can be collected more efficiently and effectively by using sensor nodes than done in existing PTS. The comprehensive architecture of P2TS is described in figure 5. Each entity in food supply chain has each HACCP system. For easy understanding, we assume that P2TS is applied to meat processing supply chain. At the farm level, EPC sensor network-based a pigsty environment management, breeding management and, other HACCP management (residue of antibiotics monitoring, medical and feed stuff supply monitoring and so on.) are possible.

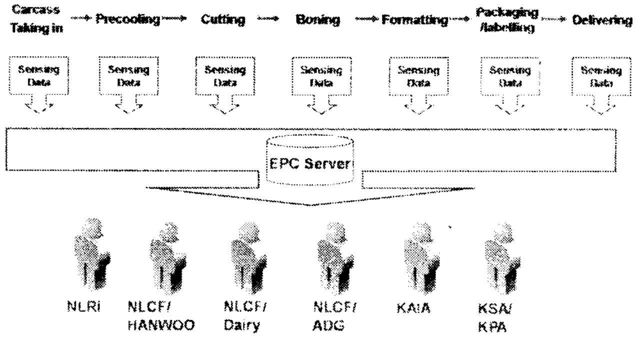

Figure 4 An Example of Collecting data in P2TS Process

At 1st and 2nd processing and, retailing phases, processing procedure monitoring, especially CCPs, and other tasks that have been conducted through RFID technologies (shipping/delivering management, inventory management and so on) are possible in P2TS. The point is that through the P2TS, we can monitor some critical points more efficiently by using EPC sensor network technologies.

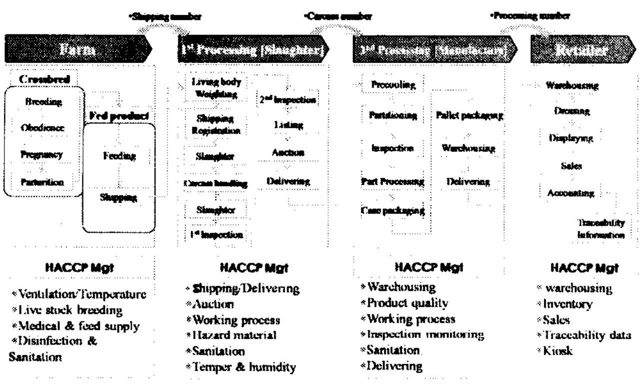

Figure 5 The Architecture of P2TS

Also, some problems in operating HACCP and PTS mentioned previously can be dealt with in P2TS. From the HACCP perspective, through automatic monitoring (sensing) of P2TS, checking and recording task can be done automatically and this results in more accurate data capturing and reducing the time to check and record the captured data.

In food industry, there have been a lot of deliberate contaminations [28]. P2TS also reduce the probability of this deliberate contamination through real time-based monitoring. In current HACCP, many conduct stop checking periodically, so that the information is relatively static. With this static information, we can not know what happen until next checking point. In contrast, P2TS conduct real time-based monitoring so that we can get relatively dynamic information. (This is different concept from dynamic data described above.) So, there should be some benefits from this dynamic information, which will be considered and studied within our future study.

Moreover, via EPC network ,which is open de-facto architecture, uniform data can be shared among partners in food supply chain so that companies can reduce information management costs and assure high quality data quality. And other operational efficiencies from using RFID also can be achieved. Table 3 shows some advantages that P2TS contributes to the current HACCP system.

Table 3 The contributions of P2TS to HACCP

	HACCP	P2TS
Operations	Neglect of duty, Insufficient time to manage, Labor error including checking and recording processes and, possibility of deliberate contaminations	Automatic checking and recording: - accurate checking & recording - time saving - other operational efficiencies, Preventing deliberate contaminations
Monitoring and corrective actions	Uncertainty of when & where faults happen, Static information from spot checking	Reducing the uncertainty, Dynamic information from continuous checking, Situation-dependent controlling
Network systems	Requires data code mapping - High cost and poor data quality , Limited controls of the supervisory officers/authorities	Unified data sharing and integrated control through the entire supply chain - Time and cost saving for observing - Closer relationship between farm staff and processing companies

Table 4 Comparison between PTS and P2TS

	PTS	P2TS
Objective Perspective	To assure consumers health and safety by enabling rapid recall and withdrawal of hazard products after crisis	To ensure product safety from farm to table and to assure consumers health and safety by preventing food crisis
Traceability Perspective	On purpose to prevent diffusion and a recurrence, Identify the source of the hazard and the cause that generated it	On purpose to prevent a occurrence itself, Identify and manage the CCPs where unacceptable hazard could be introduced into the system
Safety Perspective	Protective control-based safety management, Not improve product safety, neither its quality	Prevention-based safety management, Improve product safety or its quality.

The current PTS and P2TS are compared in terms of objective, traceability and, safety in table 4. The contents are briefly dealt with in previous part.

The figure 6 depicts the system architecture of P2TS in full food supply chain. In order to establish cost-effective system, we can use IP network including Internet and Virtual Private Network (VPN) and web service [7]. By implementing this system architecture, full HACCP in whole supply chain can be achieved in compliance with the trend. (There are indications that some governments see the adoption of whole chain HACCP [14].)

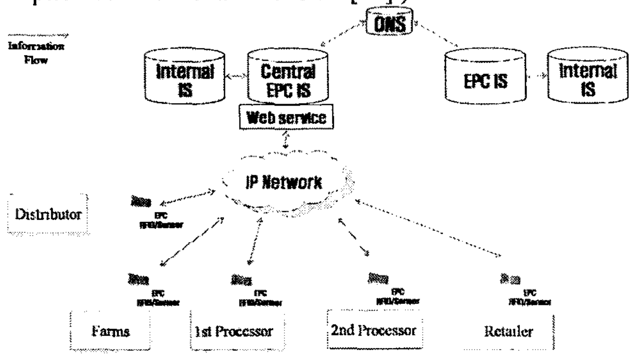

Figure 6 System Architecture

Furthermore, by using open architecture of EPC network, which is de-facto standard, companies can easily exchange traceability related data with their partners not only domestically, but also internationally all over the world.

Discussion

The effectiveness of traceability system depends on the degree of accuracy of information collected and the efficiency of the traceability system depends on the ability to collect dynamic data which is strongly related with safety and quality [21]. In this paper, we propose the more effective and more efficient traceability system than the existing traceability system; Product and Process Traceability System. By using EPC sensor network, the degree of information accuracy can be increased and by applying EPC sensor network to HACCP, the ability to collect dynamic data also can be increased. With this P2TS we can track and trace not only each product, but also each process in food supply chain. Furthermore, this P2TS has some advantages compared to the existing PTS or HACCP system.

However, it is important to mention the limitation of our study. The P2TS needs to be applied in practice in order to test its effectiveness and efficiency through practical implementation. Also, the level of difficulties of HACCP implementation is various depending on the status of information Technology (IT) infrastructure of a country and the level of consciousness of sanitation. Basically, we posited them based on Korea's level.

Future studies still remain. We will study what kinds of benefits are come from dynamic information in P2TS and draw applications from them. Also, we will study the integration concept between EPC sensor network-based quality assurance and supply chain management in food supply chain so as to get full benefit of P2TS. Finally, we should apply P2TS to the real world in order to test both qualitative and quantitative benefits.

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