The case for UHF RFID application in the meat supply chain in the Irish context: a review perspective

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Abstract: As a result of recent food scares, increasing pressure has been placed on food producing industries to incorporate a farm-to-fork traceability system. Conventional methods of traceability while reasonably successful are not without their disadvantages. These include potential damage and limited data capacity in the case of bar codes, unacceptable delays incurred through the use of DNA sampling and finally inapplicability of on biometric technologies due to permanent detachment post mortem. The aim of this paper is to assert the case for the widespread adoption of RFID in the farm-to-fork traceability of meat, all based on the Irish system. The arguments would be valid to any country or geographic region, with the existing differences taken into account. RFID technologies offer, among others, solutions to the most important challenges to barcode technology, amenity to automation, possibility of value-added products or processes, possibility for condition monitoring during storage and transport, potential to in-house traceability under adverse processing environments, seamless integration with global supply chain, item-level traceability, and all these in near real-time.

Keywords: UHF RFID, traceability, food supply chain management, electronic food traceability

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1 Introduction

Chain traceability has been defined as being the ability to trace the history, application or location of an entity by means of recorded identifications throughout the entire supply chain (Bechini *et al.*, 2008). In the context of food it involves the step-by-step recording of information that coincides with the food products physical trail (Smith *et al.*, 2005, Regattieri, Gamberi and Manzini, 2007). EU Directive 178/2002 came into force on 1 January 2005, and it makes traceability mandatory in all food business operations where it states traceability as "the ability to trace and follow a food, feed, food producing animal or ingredients through all stages of production and distribution (European Commission, 2002). Two terms are commonly referred to when discussing traceability: tracking and tracing. Tracking refers to the ability to follow the path of a specified unit and/or batch downstream through the supply chain as it passes between various trading partners. Tracing refers to the ability of the system to identify the origin of a particular unit and/or batch of product at any point in the supply chain by reference to previously stored records by trading partners, in other words, to follow the information trail. It is of utmost importance in supply chain traceability that the data flow corresponds to the product flow. The supply chain has also been described as the flow of physical goods and associated information from the source to the consumer (Ustundag and Tanyas, 2009) - a definition that has put traceability at the core of supply chain. In food supply chain, in particular, the farm-to-fork concept associated with traceability refers to

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the ability to track an individual animal from a farm through to a final packaged product and be able to trace this particular packaged product back to a particular farm. All the information contained therein relating to the product is to accompany the animal pre-processing, or the carcass post-processing, throughout processing, storage, distribution and finally to consumption of the final packaged product.

There are clear advantages of implementing these systems besides the obvious improvement in product safety and reduction in the risk to consumers' health. Such advantages include the ability to improve process control and monitoring while also directly linking final product with raw materials. This enables the comparison of the various raw materials for quality control purposes, and provides information in product recall situations. Traceability systems also have the ability to aid in the auditing process (Bertolini, Bevilacqua and Massini, 2006). RFID systems in conjunction with enterprise ERP systems have the ability to add value to organizations in terms of operational efficiencies through an efficient and fully visible supply chain which will also aid in the development of effective strategic management (Mc Carthy, 2010)

Currently, farm-to-fork traceability requirements have been put in place in various countries and regions of the world due to recent food scares including bovine spongiform encephalopathy (BSE), foot and mouth (FMD), and avian influenza. These geographical regions include all EU member states and Japan. On the other hand, countries like Brazil, Australia and Canada have mandatory or mandatory-for-export traceability systems while the USA has a voluntary system in place, although there are indications that this will change (Schwägele, 2005). The systems in Australia, Brazil and the USA cover farm of origin to slaughter while the Canadian system covers farm of origin to export and New Zealand have a "paddock-to-plate" system which uses DNA fingerprinting or more economical data capture technology (Smith et al., 2008).

This study aims to identify the challenges within the existing system, to provide a review of the potential of RFID in beef traceability, and finally make recommendations on the way forward, referencing the situation in the Irish farm-to-fork beef traceability system.

2 Literature review

2.1 The existing farm-to-fork traceability system

The following section details the existing systems currently in use paying particular attention to the Irish Industry sectioning it into the following two main sections below.

2.1.1 Live animal tracking

Traceability of meat in Ireland is currently governed by a number of regulations including: EU 178/2002, which lays down general principles and requirements of food laws; EC 1760/2000 which establishes a system for the identification and registration of bovine animals, the labeling of beef and beef products; and EC 911/2004 which governs ear tags, passports and holding registers.

All bovine animals born in Ireland have a yellow plastic ear tag labeled with an individual identification number. The owner of the animal then sends a National Calf Birth Registration form to the National Calf Birth Registration Centre for entry to a central database. This results in a National Bovine Administrative Document and a Cattle Identity Card/Passport being issued for each registered animal. This is to accompany the animal throughout its lifetime containing details such as disease testing, owners, keepers and movements. Herd owners are also obliged to keep an on-farm record of animal date of birth, ear tag number, breed, color and sex for each individual animal including movement on to or off their premises.

EC 1760/2000 (European Commission, 2000) led to the introduction of a centralized computerized database for animal traceability which requires each Bovine Registration System to contain:

(1) ear tags with a unique animal ID;

(2) a computerized database;

(3) animal passports; and

(4) registers on each holding facility.

In Ireland, this computerized system is under the control of DAFF (Department of Agriculture, Fisheries and Food). This system was set up to capture all births, movements, deaths and disposals of animals and is comprised of the following main components (DAFF, 2003):

The calf birth registration system, operational used since 1996, requires all births to be registered on a national database which holds details such as: ear tag number, sex of animal, breed, date of birth, herd of origin and ear tag number of dam; and information stored on the central database can be updated at controlled points of access including livestock markets, meat processing plants and points of export throughout the country. In addition details of all private sales are required by law to be passed into the Department's Cattle Movement Notification Agency by the farmer for eventual entry into the database.

While providing a dramatic improvement on prior traceability methods, the CMMS has some challenges to overcome. These include its reliance on hand written postal notification from individual herd owners relating to animal births and deaths. This not only makes it vulnerable to the potential of human errors due to incorrect completion of forms, it also introduces the possibility of tampering. As a result the CMMS system is unable to operate in real time, as data entries require verification (Shanahan et al., 2009).

2.1.2 Beef tracking

A recent study carried out by GS1 and a number of partners concluded that farm-to-fork traceability is possible with the use of the GS1-128 bar code (which can be thought of as both a data structure and a symbology). The GS1-128 is extensible and can be made to contain particular details such as sell-by date, expiry date, the batch number of a product, and a product's weight (GS1, 2005). This system requires the identity of each animal to be verified at the point of arrival at the processing facility and the information being entered into the host's database. The animal is slaughtered and carcass divided into both hind and fore quarters. As well as being stored on the host's database, the following details are printed onto labels that are to be attached to each quarter:

- carcass number;
- ear tag number;
- farmers name and address;
- country of origin;
- date of birth;
- factory of slaughter and date; and
- sex and grade of carcass including cold weight.

The carcass then enters processing where it is deboned and converted into primal cuts. Each primal is weighed and vacuum packed with a label containing a GS1-128 bar code which provides traceability of each particular primal cut down to a group of carcasses processed in a particular pre-determined time period. Scanning of the bar code at this stage prior to and at the point of removal from cold storage provides information on the primal's cold storage duration, which is also recorded as part of the traceability mechanism.

At the distribution stage, one of two approaches is taken in relation to the labeling of beef depending on whether:

(1) the primal is delivered to a butchery department for further packaging; or

(2) the primal is not packaged and is sold over the counter in unpackaged units.

In the first case, the GS1-128 is firstly scanned at retail level to confirm receipt and also to transfer all traceability information onto the individual store's database which makes all traceability information available to the store manager. The primal is again placed into cold storage at the retail store, whereby barcode is scanned both when the primal is placed into, and removed from the cold storage facility. This procedure is also repeated during time of packaging. Considering each day as a single unit and assigning it with a "daily lot number", each item of packaged meat sold within a particular unit of time possesses a unique reference number that makes possible the traceability of the pack of meat back to the batch of animals from which it originated.

In the second case, where the product is on display with no packaging the following occurs. When removed from the cold store the primal's unique GS1-128 label is scanned into the system. This system then allocates a lot number to the primal used for serving, again with a unique time stamp. Up on purchase, a portion of meat is then packaged for the consumer and the lot number is automatically printed on the price label linking the purchased product to a particular source and a time stamp - thus providing traceability. Copies of these labels are also stored in a log book ensuring integrity of the supply chain for the retailer (GS1, 2005).

As can be seen above, data transfer along the supply chain has been done by paper record, ear tags, or by the use of the conventional bar code. Paper records are no longer an option in supply chain management due to its many disadvantages. These include little or no level of automation, a heavy dependence on human input which has been proven to be time consuming and prone to errors due to mis-recording of the information or in some cases the information not being recorded. Paper recording cannot provide real time analysis which may leave consumers vulnerable to illness due to inaccurate or slow product recalls. The use of ear tags, despite being a well established technology have resulted in cases of legibility problems due to mud and/or other materials obscuring the unique code (Edwards, Johnston and Pfeiffer, 2001). Ear tags have also raised some ethical issues as their application may distress the animal and has been proven to result in permanent damages to the ears of sheep (Edwards and Johnston, 1999). While proving useful due to its low production cost, and global acceptance, this technology poses many challenges. Bar codes are restricted by a low data-capacity and their use may prove time consuming on a commercial scale due to their need for a direct line-of-sight between bar code and reader. They are also prone to damage in harsh production environments due to warping, over handling, high moisture and abrasive damage rendering it unreadable (Ayalew et al., 2006). These systems also do not possess the ability for multiple reads (Lahiri, 2006). The non real-time functioning of supply chain management systems means the systems function on reactively and not proactively which negates the need to protect the consumers.

2.2 Radio frequency identification as an alternative

As has been shown above, barcodes, despite being established technology, and low cost product identification technology face serious challenges in relation to their physical integrity, and data capacity. The fact that they require a line of sight for operation also limits their utility in cases where multiple products pass a scanning station. On the other hand, RFID solves these issues and is still a developing technology to overcome the remaining minor obstacles, as well as add new opportunities, in relation to its applications in the supply chain.

RFID technology dates back to the 1940s and it is suggested application to live stock applications dates back to the mid-1980s when the Dutch Government wanted unique identification of around 75 million pigs, paving way to electronic tags (Ollivier, 1996). More recent reviews of the technology in relation to animal identification such as that by (Artmann, 1999; Kampers, Rossing and Eradus, 1999) are also notable which provide amongst other aspects, a full description of RFID in the identification of animals. Related to this EU regulation 21/2004 required all small ruminants born after July 9 2005 have to be identified by displaying their EU member code accompanied by a 12 digit animal code and it also states that from the year 2010 one of these methods will have to be delivered via electronic identification (European Comission, 2004).

In addition to animal identification it has enjoyed successful incorporation into different applications including building access control, supply chain tracking, automatic toll collection, parking access, retail stock management, library book tracking, vehicle immobilization and theft prevention systems (Roberts, 2006), transportation, waste management, mining industries, construction, aviation, food and health industries (Chao, Yang, and Jen, 2007; Ngai et al., 2008). At its most basic an RFID system consists of a reader responsible for launching an electromagnetic (interrogation) wave into the surrounds, and a tag that is attached to a product being tracked, and that sends back its identity through one of a few mechanisms, in response to the interrogation signal. In the case of passive UHF

RFID tag a signal is reflected back to the reader antenna, through a mechanism known as backscatter. A sequence of variations, the pattern of which is determined by the integrated circuit at the core of an RFID tag, forms the ID information to be sent to the reader for demodulation (Fan et al., 2007). In more advanced tags, exploitation of tag circuitry and manipulation of coupling offers the opportunity to record certain storage conditions such as temperature and moisture content, thus offering the producer and retailer the ability to accurately predict the shelf life of a particular product (Montanari, 2008).

The advantages of RFID originate from its capabilities to deliver a high level of automation to the food supply chain as opposed to conventional technologies combined with its ability to transport data on each individual tag along the supply chain. Other major advantages of this technology in the supply chain include:

- compliance with electronic product code (EPC) protocol facilitating a smoother integration into the global supply chain;
- tags can remain fully updatable throughout the supply chain;
- potentially an environmentally friendly method of traceability when used with multiway (re-usable containers) systems;
- reductions in labor cost (for example, 8.5 million pound in a year, as predicted by Sainsburys, (Karkkainen, 2003) and a 2 to 3 years pay back period), in lost sales, out of stock issues, human errors and paper work (Sahin, Dallery and Gershwin, 2002; Tajima, 2007);
- no established line of sight required between tag and reader;
- the possibility of multiple tag reads per interrogation;
- the potential of a traceability technology for modified atmosphere packaged meat down to item level (Mc Carthy *et al.*, 2009a; Karkkainen, 2003).

However, a major drawback of global adoption of UHF RFID for the tracking of food items has been the attenuation and reflection of the propagating electromagnetic waves in the presence of materials such as metals and high moisture content substances (Mc Carthy, 2009) which are in abundance in modern day processing facilities. This is further complicated by the fact that no two antennae posses the same gain pattern thus increasing coupling inconsistencies (Leong, Ng and Cole, 2006). Despite these shortcomings in the technology it has been predicted that RFID will be commonplace in meat packaging technology as a method of smart packaging (Kerry, O'grady and Hogan, 2006).

For the sake of convenience, the discussion of the supply chain “farm-to-fork” of meat, in relation to the main types of identification technology being used, has been divided into three segments, namely birth to slaughter; slaughter to processing; and finally storage, distribution and retail. In the following sections it is attempted to outline the various identification and data carrying media employed in modern manufacturing and propose, by means of highlighting the advantages of UHF RFID, its adoption as a data carrying technology in the meat supply chain.

2.2.1 Birth to slaughter incorporating RFID

As is mentioned in a previous section, current methods of identification and verification of the live animals make use of ear tags and accompanying documents such as passports. A report on the possibility of the introduction of electronic identification for bovine and buffalo animals carried out by the European Commission recognized RFID as a desirable method of bovine identification (European Comission, 2005). The report dealt with three types of RFID transponder design:

- electronic ear tag - leading to faster, and automatic data capture, and low reported failure rates (0.63%), but increasing with age (2.3% after 14 months);
- ruminal bolus, - an RFID tag placed in the rumen, and to remain there for the rest of the animal’s life. Reported failure rates were constant (at 0.35%), but varying with age of initial implantation. Garin, Caja and Conill (2005) also reported dependence of success of application in lambs on implanting age; and
- injectable transponder – applied subcutaneously, which was also resulted in a low failure rate (0.7%, in

creasing to 1.0% at one month post-tagging, and again decreasing to a constant level of 0.3%, thereafter).

Recovery rates varied from between 80% for injectable transponder (worse, with only 52% of those recovered being readable) to 100% recovery rates for electronic ear tags and ruminal boluses. One outstanding feature of ruminal boluses is that they are virtually tamper-proof as they can not be physically accessed while the animal is alive.

2.2.2 Slaughter to packaging incorporating RFID

Traditionally, this phase is one of the most challenging sections of the supply chain due to the fact that each single carcass may end up in as many as 150 different components as well as the fact that off-cuts are commonly mixed together from different sources making traceability nearly impossible (Smith et al., 2008). On the other hand, during this stage the meat is processed and stored in a challenging production environment, demanding a durable and robust data carrier.

Dating linear barcodes has been the most widespread method of tracking during this phase due to their low production cost; the fact that they are well established technology, despite the difficulties mentioned above (Ayalew et al., 2006) which provide a comprehensive summary of bar codes currently in use and their properties. In addition, a variety of solutions have been proposed to improve applications of barcodes as a method of traceability, such as that demonstrated by (Smith et al., 2008) to use barcodes for time keeping. Animals were grouped into batches and assigned a group lot ID (GLID) and were processed collectively as groups. However, they also expressed concern that this system may not be effective in larger processing plants as it would disrupt processing, and it is also limited by the constraints of bar code technology itself.

Clark et al. (2006) and Singh et al.(2008) reported that the effect of the item being packaged had a significant effect on system coupling capabilities favoring lossless or reflective products which was confirmed by (Mc Carthy et al., 2009a) who concluded that the composition and location of the packaging in relation to the tag had significant effects on RFID coupling. A more recent investigation (Mc Carthy et al., 2009b) reported detection rates of up to 88% depending on a number of factors including tag design and/or orientation, reader antenna polarization, and speed of conveyor.

The use of RFID in combination with a “smart” conveyor system has been reported by Mousavi et al. (2005). This consisted of the carcass being hanged on a hook (bead) to begin its way through processing on a conveyor system; each hook had an RFID tag embedded containing a unique code which acted as an index to a database which has stored the traceability history of the source animal up to that point in time and facilitated data updates during production, should the need arise. This identification was unique to each carcass and is only for use within the processing facility. As the carcass progressed through processing, supplementary RFID tags were then programmed and attached to individual carcass components.

Another added value of RFID technology is its ability to direct certain more expensive sections of the carcass to particular areas of the processing plant, or to more experienced processors thus reducing waste. It is reported to have provided 100 % traceability of prime cuts in cases where the carcass is delivered to the retailer in prime cuts. This system is reported to have potential application to other sectors of the food industry.

2.2.3 Storage, distribution and retail incorporating RFID

There have been a number of methods proposed in relation to maintaining the integrity of the data transfer throughout this stage in addition to the widely deployed bar code. This technology being prone to the harsh production environments, are susceptible to damage as a result of the high levels of handling at this stage of processing. Jansen and Krabs (1999) have proposed the incorporation of RFID into the packaging of the final product which will be returnable (multi-way system), and enabling maintenance of electronic data transfer throughout the processing stages, and as a result throughout the supply chain.

Another method proposed by Martínez-Sala *et al.* (2009) incorporates the use of batch traceability through the use of a system known as MT, developed by a Spanish company named ECOMOVITSTAND. This involves each product being placed on a returnable shelf with an RFID chip embedded. Manufacturers claim this technology has the ability to be used for the entire product cycle. The two methods mentioned above will only prove cost effective if the shelves and/or the packaging (depending on the systems incorporated) are actually returned due to their initial high manufacturing cost.

RFID will also offer the advantage of being able to automatically monitor the storage conditions of the tagged items at regular intervals throughout storage and transport (Bridge, 2008). This will offer the recipient of the goods the ability to accept or reject the goods on arrival if a safety breach has occurred during transit.

To summarize, deployment of RFID along the farm-to-fork chain solves the major technical problems associated with barcodes, facilitates automation, enables added-value beef products creation, saves cost, allows data-logging of storage and transport condition thereby facilitating condition monitoring, allows internal (in-house) traceability, and offers the possibility of seamless integration with the global supply chain, with each portion of beef individually identified – all at least in quasi-real-time.

3 Conclusion

The case for RFID implementation of bovine and beef traceability has been outlined. UHF RFID technology has the ability to add value to the supply network of organizations due to the inherent high levels of automation offered to end users. It is now clear that UHF RFID technology has the ability to add value to the meat supply chain in relation to each of the three relevant sections within this document and also within the meat production cycle, facilitates automation, storage and transport. The ability of the technology to monitor environmental conditions of the product results in elevated product safety and consumer confidence. The full potential of this technology will only be realized by widespread adoption across the value network, a trend that is not currently being exploited on a commercial scale. The implementation and maintenance of a traceability system requires a multi-disciplinary approach to address legislative requirements, technical aspects of data capture, storage and transfer along the supply chain; as well as the economic analysis of the traceability system. It is for this reason that widespread adoption will increase chances of a successful adoption of RFID technology in the meat industry and help realize the full potential of the technology. It is time that early moves are made toward the adoption of this technology in the meat supply chain.

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