International Food and Agribusiness Management Review
Special Issue - Volume 19 Issue A, 2016

Enhancing Food Safety, Product Quality, and Value-Added in Food Supply Chains Using Whole-Chain Traceability

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Abstract

A robust whole chain traceability system can limit consumers' exposure to potentially hazardous foods, improve supply chain management, and add value to consumer products. However, fragmented supply chains present special challenges. In the beef industry, for example, producers have resisted participation in whole chain traceability because of high cost relative to value and concerns about disclosing proprietary information, among others. A multi-disciplinary team from universities, private firms, and a foundation has developed and tested a pilot proprietary centralized data whole chain traceability system that addresses many of these obstacles. This system would facilitate a precision agriculture approach to beef production and marketing. While the remaining challenges are serious, the benefits to society, consumers, and businesses from widespread adoption of whole-chain traceability systems are potentially large.

Keywords: whole chain traceability, fragmented supply chains, MarketMaker®, proprietary centralized data, food safety, product recall, value-added, product tracking, biosecurity, big data

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Introduction and Motivation

A robust whole-chain traceability system can provide the foundation for a targeted and timely product recall after a food-borne illness outbreak. It can limit consumers' exposure to potentially hazardous foods and strictly limit a company's liability.

In the beef industry, one of the best-known food-borne illness outbreak examples is the 1992–1993 incidences of Escherichia coli O157:H7 illnesses stemming from undercooked hamburgers served in Jack-in-the-Box restaurants. Foodmaker, Inc., owner of Jack in the Box, issued a recall but ultimately only recovered 20% of the potentially contaminated meat. In the aftermath, Foodmaker lost approximately $160 million in sales and 30% of its stock market value, and subsequently paid tens of millions of dollars to settle individual and class-action lawsuits (Soeder 1993). The CDC conducted a traceback in an attempt to discover the source of the contaminated beef. The CDC identified six separate slaughter plants (five in the US and one in Canada) as the likely sources of the contaminated ground beef (CDC 1993). Animals slaughtered in US plants were further traced to farms and auction houses in six states. The CDC was not able to identify a specific slaughter plant nor farm associated with the contaminated beef. If there had been a robust whole-chain traceability system in place it might have limited human suffering and financial losses.

Another example illustrating the difficulty of beef recalls in the absence of full traceability capabilities is the XL Foods beef recall. In 2012 it was discovered that as much as 2.5 million pounds of beef product involved in the recall issued by the Canadian company had entered the United States and had been distributed in at least eight states (Goetz 2012). The recall was further complicated by the possibility that companies could have used the recalled product to produce other products such as ground beef, ground beef patties, beef jerky or pastrami. Eventually recalls were issued for steaks, roasts, and ground beef products from US retailers including but not limited to Safeway, Sam's Club, Walmart, Albertson's, Fred Meyer, and Kroger (Bottemiller 2012). This incident resulted in the sale of the plant identified as the source of the contamination and payment of millions of dollars to settle lawsuits (Food Safety News 2016). An independent review concluded in part that XL Foods was not prepared to handle a large-recall multi-country incident (Lewis et al. 2013).

A whole chain traceability system would allow sources of contamination in the supply chain to be identified and unsafe food recalled because information could be traced end to end (McKean 2001; Smyth and Phillips 2002). Although the Bioterrorism Act of 2002 requires one-up, one-down traceability, a firm-by-firm traceback in the event of a food safety or bioterrorism event is inherently slow, even with good records at each supply chain node. As part of the Food Safety Modernization Act of 2011 (FSMA), each step in the food supply chain is required to keep its records in digital form in addition to or instead of paper to make the records more accessible to government officials. However, this change in itself is likely to only modestly increase the speed of what would still be a firm-by-firm traceback. A robust whole-chain traceability system is needed that facilitates rapid information transfer up and down the supply chain.

The technology for such a system is available. Golan et al. (2003) noted more than a decade ago that "…retailers such as Walmart and Target have created proprietary supply-chain information systems that their suppliers must adopt" (p.17), observing, moreover, that these are not just for packaged products but for the flow of raw agricultural inputs and outputs. The authors suggested that the private sector has significant capacity for tracing, with incentives to trace for food safety and quality control, for differentiating and marketing foods with credence attributes, and supply chain management. Systems such as these are typically in vertically integrated or tightly controlled supply chains. Many vertically-integrated supply chains are able to effectively trace backward and track forward because information flows within the same company.

When a supply chain is fragmented, though, transactions occur across several companies or continents, and technological and institutional constraints make tracing and tracking products exceedingly more difficult. In order to achieve whole-chain traceability, a firm at one stage needs to share information with the firm at the next stage and in turn through each firm/stage of the supply chain. The more information that is shared, the better the supply chain coordination—but the greater the risk that the information can be used by competitors. As Crandall et al. (2013) noted, deep-seated concerns by firms of disclosing their proprietary information is a key obstacle to implementing whole-chain traceability systems in fragmented supply chains. Other obstacles include perceptions that cost of implementation and operation are greater than value, lack of standards for sharing information, and potential for increased liability. These obstacles have severely limited potential participation by firms in whole-chain traceability systems, thus greatly limiting value of traceability for improving food safety and improving value to consumers. If few firms participate, even technologically-advanced traceability systems accomplish little – data that is not collected cannot be used.

Because many of these obstacles to adoption of whole-chain traceability have been observed clearly in the beef supply chain, leading to abandonment of the National Animal Identification System (Schroeder and Tonsor 2012), this article:

1) highlights key benefits and challenges of implementing a whole-chain traceability system for beef supply chains;
2) describes a technology designed (a proprietary centralized data whole-chain traceability system, or PCD-WCTS) to address the identified obstacles and challenges of implementing a whole-chain traceability system in fragmented supply chains; and
3) identifies remaining challenges for implementing whole-chain traceability systems in fragmented supply chains.

Although the specific application described here is to beef cattle supply chains, the PCD-WCTS technology is readily adaptable to other supply chains. To illustrate the potential for adding value to other food supply chains, the article describes an interface between PCD-WCTS and a private company's traceability system (which allows two-way communication between producers and consumers), as well as a planned value-added interface between PCD-WCTS and MarketMaker®, a web-based platform for matching buyers and sellers of a range of food products and commodities.

Food Safety, Big Data, and Whole Chain Traceability

Big Data analytics is the process of examining large data sets containing a variety of data types to uncover hidden patterns, correlations, trends, customer preferences and other useful information. The use of such data, including data generated by a WCTS, offers great potential for improving food safety. The CDC estimated that there are 47.8 million cases of foodborne illness in the United States and more than 3,000 affected persons die every year (Scallan et al. 2011). The World Health Organization (WHO) estimated that worldwide there are 2.2 million deaths every year from diarrheal food- and water-borne illness, with almost 90% of those deaths being children (WHO 2015). These are staggering statistics of the burden of food- and water-borne illness, but they are largely preventable with currently available technology.

Large data sets now exist that provide the opportunity to change from a mindset where the majority of our food safety resources are focused on routine testing to an informed mindset where the limited resources of regulators and the food industry can be targeted in a proactive manner to minimize the risks of occurrence of food borne illness. Noteworthy examples include:

> whole genome sequencing, which permits more rapid identification of disease-causing pathogens and matching with specific sources (Dumitrescu, Dauwaldera, and Linaa 2011; Köser et al. 2012; den Bakker et al. 2015; Inns et al. 2015; Orsi et al. 2008; and Stasiewicz et al. 2015); real-time internet searches of social media, which may allow speedier identification of illness outbreaks (Grein et al. 2000; Heymann and Rodier 2001; Wilson et al. 2008; and Wilson and Brownstein 2009); and Geographic Information Systems (GIS), which can help identify potential problems and adjust production to reduce those problems, and help predict outbreaks using location and weather data (Scallan et al. 2011; Beuchat 2006; Fremaux et al. 2008; and Johnson et al. 2003).

Accordingly, beginning with HACCP (Hazard Analysis, Critical Control Points) in the late 1990s, traceability and information management have become central to both voluntary and mandated food safety efforts. The principles of both the food industry's Global Food Safety Initiative (GFSI) and FSMA are undeniably tied to whole-chain traceability and data management to support traceability. As Golan et al (2003, 18) stated, "(p)roduct-tracing systems are essential for food safety and quality control."

Using big data analytics, a well-functioning WCTS could capture producer data and interface with other data generated along the supply chain, including consumer data. This large data repository could be used for analytics and visualization. Data analytics algorithms could be used to analyze anonymized data from producers, processors, distributors, vendors, and consumers to create an early animal disease, food safety, and bioterrorism detection system. Along with disparate data sources, they could be used for prediction (predicting food outbreaks), clustering (identifying clusters of outbreaks), associations and correlations (associating food outbreaks with environmental or other conditions), classification (classifying the extent and seriousness of the outbreak), optimization (based on customer preferences or actions during an outbreak), sentiment analysis (determining the sentiments of customers at different stages of the outbreak), to name a few possible applications for food traceability. This can result in faster, better decision-making, facilitating more effective and quicker responses to food outbreaks.

In addition, data visualization can be used to place the data in a visual context to help people understand the significance of the data. Visualization-based data discovery tools allow users to mash up disparate data sources to create custom analytical views. These tools will support creation of charts and maps as well as interactive, animated graphics on desktops and mobile devices. Such tools can visualize the extent of an outbreak in the form of a map, the rate of spread of the outbreak in the form of an animated graphic, and the populations affected as a chart.

WCTS data may also be exported to decision-based systems such as a beef productivity system that could recommend feed rations to improve meat tenderness, and data on carcass and growth performance of progeny of individual cows could flow back upstream, allowing for improved management of those cows. The data can be used to refine estimates of expected progeny differences (EPDs) for important traits, ultimately improving value added to consumers.

While the importance of whole-chain traceability systems is widely recognized, the food industry has also recognized the challenges of implementing them. Fritz and Schiefer (2009) aptly stated “the establishment of tracking and tracing capabilities meets many barriers that have prevented their broad based use beyond what is legally required.”

Consumer responses to food safety concerns, their food safety expectations, and willingness to pay for food safety attributes/practices have been acknowledged in numerous studies (e.g. Bitsch, Kokovic, and Rombach 2014; Lim et al 2013; Yeung and Lee 2012). However, it is also important to understand how consumers perceive the shared responsibility for maintaining food safety standards. A 2010 survey by the International Food Information Council (IFIC 2010) found that consumers place the responsibility for ensuring food safety on all active and regulatory participants in the food marketing chain, but primarily government (identified by 74% of respondents), food manufacturers (70%), farmers/ producers (56%), and retailers/food service (49%).

Ng and Salin (2012) noted that “food safety is an inherently complex agribusiness problem (p.22),” and that safety of a final product is determined by all the production, handling, processing, and retailing practices by all firms involved. Their institutional model helps explain how management decisions by each firm can achieve competitive goals such as profitability and market share, while still achieving the public’s need for food safety. In such a complex system, traceability is only one tool in promoting a safer food system. However, it is a vital tool, as noted by IFT’s (2009) technical report, which found that all fifty-eight companies in their study sample “…acknowledged the importance of an effective (rapid and precise) product tracing system in safe guarding their supply chain (p.2).”

Whole chain traceability systems can be extremely complex, especially in the case of processed foods. In processed foods, different lots of various raw materials are combined into several production batches that are distributed to numerous points of sale (Hu et al. 2013). Thus, processors must record data not only on the product but also on the processes that impact the product, such as transport, storage and sales (Kim et al. 1995). Traceability systems must support both tracking and tracing, where tracking follows a product along the supply chain with records being kept at each stage, while tracing is the reverse process (Thakur and Hurburgh 2009).

Golan et al. (2003) argued that even without mandated traceability, firms in the United States have several motives for establishing traceability systems and, as a result, private-sector traceability systems are extensive. They suggested that firms establish product tracing systems in order to: 1) improve supply-side management; 2) differentiate and market foods with subtle or undetectable quality attributes; and 3) facilitate traceback for food safety and quality. Widespread adoption of an interconnected WCTS could provide even more valuable information specifically suited for tracking food safety events, tracing them quickly back to their source(s), and even predicting events further down the supply chain (Bhatt et al. 2013; Golan et al. 2003; Golan et al. 2004).

There are numerous traceability systems in the US within vertically integrated companies. However, the majority of the vertically integrated companies with traceability systems share limited or no information with outside companies unless ordered by a court. This is generally to protect information that companies view as critical in maintaining their market share. The challenge is even greater in fragmented supply chains, in which products pass from one stage to another, often with a change in ownership. Even large buyers face input supply chains with stages that are difficult to link together in a traceable manner. The comprehensive traceability review of the seafood industry by Sterling et al. (2015) recognized this, noting that internal traceability systems that allow companies to trace within their own operations were common in the seafood industry, but that the ability to trace transactions from firm to firm was much less common.Sterling et al. (2015) highlighted important traceability success and profitability determinants, noting the irony that the more important and imbedded traceability is in a businesses' operations, the more challenging it is for them to quantify its value. This may help explain why some firms do not see enough value in traceability to adopt it. In fact, in their recommendations section the authors noted that a significant portion of the seafood industry is made up of fragmented supply chains, and that the majority of these businesses did not see value in traceability. Sterling et al. (2015) called for future research to help those businesses "…better understand how traceability helps manage risk, reduce costs, and increase relative competitive position" (p.241).

Benefits of a Whole-Chain Traceability System in the Beef Supply Chain

Implementation of a WCTS potentially brings several benefits to a company, an entire industry, and society. Both domestic and foreign purchasers of a company's or US food products can have increased confidence in the safety of those products, increasing demand for them. This can improve sales and profitability for the industry (Sterling et al. 2015; USDA-AFIS 2009). However, an especially valuable benefit of implementing a WCTS in a supply chain may be increasing value added to consumers and to other supply chain participants. Traceability systems are commonly used within a vertically integrated or tightly coordinated supply chain for quality control and other benefits of supply chain management (Golan et al. 2003; Golan et al. 2004), including, in the case of livestock, improving animal disease traceability.

Whole chain traceability can also improve supply chain management in fragmented supply chains (Sterling et al. 2015). In the case of livestock, Schroeder and Tonsor (2012) observed that animal identification (ID) and traceability systems have developed rapidly around the world, and that most major beef export countries have created animal traceability systems to better protect animal health and to enhance export market growth. Tonsor and Schroeder (2006) noted that an example of a successful whole-chain traceability system for beef is Australia's Traceability and Meat Standards Program and National Livestock Identification System (NLIS). In that system, 99.5 percent of movement transactions are electronically recorded within twenty-four hours of the transaction. It is claimed that the NLIS has created market opportunities for Australia's beef industry amounting to hundreds of millions of dollars (AUD), partly because the NLIS has increased the perception by importers that Australian beef is dependable (VCM International).

The Australian system is also estimated to have led to $200 million (AUD) in net benefits since its introduction by improving value added to consumers. Specifically, by tracking and comparing cattle performance, consumers were statistically more likely to have a "more pleasurable eating experience" (VCM International 2014, 15). Although the Australian NLIS has reportedly been very successful, it has come in part through government mandates following a food safety event that resulted in a quarantine of Australian beef and in part because Australia's heavy dependence on exports led to greater motivation by industry participants (Tonsor and Schroeder 2006).

Estimates suggest that the US beef industry also would experience positive results if it adopted whole-chain traceability. Some of the most comprehensive economic assessments of the value of a national animal identification and traceability have focused most heavily on the role of such a system in avoiding the large costs of reduced exports in the event of an animal disease event. Schroeder and Tonsor (2012) summarized the considerable efforts of the livestock industry and US government agencies in an attempt to establish a National Animal Identification System (NAIS), efforts that gained traction with the 2004 discoveries of BSE ("mad cow disease") in Canada and the United States, but that ultimately were abandoned in 2010.

One might ask why the US did not mandate traceability as did other countries such as Australia. The answer to that question is beyond the scope and purpose of this article, but others have dealt with this issue. Goldsmith et al. (2003), for example, identified historical and political differences leading to differences between European Union and United States approaches to food safety regulation, and developed an institutional model to help understand variations across food safety policy environments.

Ortega and Peel (2010) noted that since animal health programs are part a broader set of human health and food safety systems, there is a public nature to animal ID programs (a basic form of traceability), and that this strengthens the argument for a mandatory system, as well as public investment in such a system. They also observed, though, that implementation of an animal ID system has been politically difficult in many countries for social and cultural reasons, but also because of multidimensional factors affecting costs and benefits, which make it difficult for producers to fully value the uncertain benefits of animal ID relative to its certain costs.

Here, we assume that political realities are such that a traceability system for beef will not be implemented by mandates alone, so the focus of the technology is to reduce costs and increase benefits to individuals to make participation attractive. One could also view increasing the economic attractiveness of traceability as reducing the combined economic and political barriers to participating, which might mitigate negative response to mandated traceability.

To show the potential value of a traceability system for the beef industry, Schroeder and Tonsor (2012) cited estimates by Coffey et al. (2005) that the beef industry had lost $3.2 billion to $4.7 billion in just one year, 2004, due to export restrictions alone after the BSE discoveries. Similarly, Pendell et al. (2010) estimated that if lack of traceability resulted in at least 25% of beef product being unacceptable in international trade, the US could lose a total consumer and producer surplus of $6.65 billion. Viewing those results from another perspective, a 1% increase in domestic demand or 34.1% increase in export demand would fully cover the cost and surplus loss of adopting a traceability system that achieved a 90% participation rate. Even with a 70% participation rate, the research showed that there would be a net benefit to producers of $9.26/head (NAIS 2009). Thus, overall industry benefits would be quite high relative to costs of implementation. These results supported earlier results by Resende-Filho and Buhr (2006) that showed the positive impacts of traceability in the beef and pork industry when substantial negative food safety news is reported by the media, by comparing revenue under the assumption the country has adopted a beef and pork National Animal Identification System with an assumption of no traceability system.

The USDA-APHIS (2009) report on NAIS highlighted other key benefits of an effective animal identification and traceability system, including the ability to establish containment areas to restore market access, increased transparency and reduced information asymmetry in the supply chain, improved value added efficiency, and enhancement of animal welfare in response to natural disasters. That report did not provide dollar estimates of these benefits. Indeed, as Sterling et al. (2015) noted, benefits to individual firms of participating in a traceability system are inherently difficult to calculate.

The USDA-APHIS (2009) report also noted that countries importing beef are increasingly adopting animal traceability systems for their domestic production, and that such systems are becoming requirements for market access. The report suggests that the United States lags behind world standards for animal ID and traceability, and that without traceability the US would face future challenges in maintaining or increasing beef exports.

From the perspective of value to consumers, studies by Lee et al. (2011), Loureiro and Umberger (2004), Angulo and Gil (2007), and Dickinson and Bailey (2005) showed that consumers on average are willing to pay some premium for traceable beef products. These benefits can be partially transferred to producers. However, few studies have been conducted on the benefits of traceability to the producers who would have to pay for traceability.

Challenges in Implementing a Whole-Chain Traceability System in the Beef Supply Chain

Golan et al. (2004) note that even though society or an industry as a whole would benefit more than the costs of implementing a traceability system that does not necessarily imply that individual supply chain participants would receive a net benefit. This is especially true in fragmented supply chains (Sterling et al. 2015; Bhatt et al. 2013). Seyoum et al. (2013) expanded on beef industry research by Blasi et al. (2009) and Butler et al. (2008), estimating that most of the costs of implementing a WCTS would fall on cow/calf producers, the first link in the supply chain but also the smallest producers. Conversely, most of the benefits would accrue to larger producers and processors further down the supply chain. This result confirmed the perceptions of some producers that costs would be greater for those that could least afford them.

Specifically, Seyoum et al. (2013) estimated that the costs to an individual producer, including the costs of RFID eartags, installing the eartags, and amortized costs of RFID readers (but not including costs of the overall system) range from $5.95/head for small cow/calf producers to $0.41/head for cattle feeders with more than 8,000 head. Costs for small cow/calf producers are fourteen times larger than for large cattle feeders because, as the first stage in the supply chain, they pay for the RFID eartag and its installation, and because fixed costs of RFID readers and other equipment are spread over fewer animals.

Benefits, on the other hand, are more likely to be realized by processors and downstream producers. For example, any premium for tender beef would be received by processors, and gains from improved feeding efficiency would be realized by cattle feeders, even if the higher value originates from improved genetics provided by cow/calf producers. Producers contributing the increased value who are one or more stages removed from the stage at which the benefits are realized are less likely to be rewarded for those contributions. Thus, those producers who bear the biggest proportion of the cost of traceability are also likely to receive the least benefit. This illustrates part of the problem with fragmented supply chains, and explains part of the reluctance of many beef producers to participate in the NAIS. It also explains the conclusion by Schroeder and Tonsor (2012) that existing voluntary traceability systems for beef offer producers the option to target export market opportunities, but that to capture those opportunities the entire vertical supply chain from cow-calf producer through exporter must be closely vertically aligned.

As previously noted, although a National Animal Identification System likely would have generated societal benefits far above its costs (Schroeder and Tonsor 2012), when USDA attempted to implement the NAIS in the mid-2000s, many producers resisted, partly because of this perceived cost inequity but also because they did not want to reveal proprietary information that could be used against them by competitors or government agencies, and they believed the costs exceeded the benefits. (Schroeder and Tonsor 2012; Crandall et al. 2013; Adam et al. 2015). These and other factors led to abandonment of the NAIS efforts in 2010 (Schroeder and Tonsor 2012).

Producers participating in a WCTS also face an increased liability risk. In the absence of a WCTS, a food safety event might be traced back to a processor, who bears the cost of recalls and lawsuits. The ability to trace the source of an event back to individual producers, while potentially improving food safety in the supply chain, exposes those producers to risk that they would not face if they did not participate in a WCTS (Golan et al. 2004; Pouliot and Sumner 2008; Crandall et al. 2013).

Implementation costs are composed of cultural, sociological, political, and economic components. Some of these may be actual, quantifiable costs, while others may be based on perception. Ultimately, the key to implementing voluntary WCTS in fragmented supply chains is that incentives must exceed costs for all supply-chain participants.

PCD-WCTS Technology – One Proposed Solution to Resolve Traceability Issues in Fragmented Supply Chains

USDA's National Integrated Food Safety Initiative (NIFSI) funded a multi-institution, multidisciplinary research project to address these fragmented supply chain issues by developing a pilot scale proprietary centralized data whole chain traceability system (PCD-WCTS) technology for beef cattle. The fundamental design criteria included: 1) stakeholder feedback incorporated into the design; 2) proprietary data, in which entities that enter data into the system, own the data, and control access to that data; 3) centralized data, for greater system integrity and data security; 4) data immutability, in which all records are immutable once an animal or product changes ownership; 5) system is internet based; 6) integrated traceability and product marketing; and 7) system adaptability to non-beef products. The following sections describe the beef cattle pilot-scale PCD-WCTS technology and how it could potentially help resolve obstacles in implementing WCTS in fragmented supply chains, and then highlight remaining challenges for effectively implementing a national-scale version of the technology.

The key advantage of PCD-WCTS, compared to previously attempted and current systems, is one of the level of data access control—the parties putting information into the system maintain granular privacy control over their data. In other words, users putting data into the system decide both who can see that information and what pieces (granules) of information they can see. This is critical, since the ability to trace food through a supply chain depends on private firms sharing product information with competitors as well as collaborators. Moreover, this would address the necessity (noted by Schroeder and Tonsor 2012) of tightly-controlled supply chains for capturing value-added opportunities.

PCD-WCTS as a Data Management System - Features and Capabilities

At the heart of PCD-WCTS is a DBMS (DataBase Management System) that provides a secure filing system for data contributed by PCD-WCTS stakeholders. PCD-WCTS data is housed in a MySQL database located on a Linux server. As a data management system, it is designed to interface with a range of other data input mechanisms. For example, an app for the Apple iPad family of devices has been developed that permits users to access their accounts.

A core component of the system is the database mapping module. This module facilitates interfacing PCD-WCTS with other traceability systems. For example, the pilot version of PCD-WCTS directly interfaces with the traceability system operated by Top 10 Produce LLC d/b/a Beefy Boys Jerky Co. Top 10's system permits producers (its current clients produce oranges, avocados, strawberries, and other fruits and vegetables, as well as beef cattle) to share photos of themselves and their farm, information about how the products were grown, recipes, and any other information the producer believes consumers might want. Food-conscious consumers can view this information simply by scanning the QR code on the product at the grocery store with their smartphones. Consumers can in turn provide real-time feedback to the producers about the quality of the product, or ask questions about the product and how it was raised.

The interface with PCD-WCTS permits Top 10 to extend its relatively short supply chain both downstream and upstream through multiple stages, expanding the number of participants that can access its system even if they are several stages removed. Similar interfaces could be developed with any other traceability systems that need the data management features of PCD-WCTS, as long as the product can be identified digitally.

Ability to Selectively Share Specific Data

Since data stored in PCD-WCTS is owned by the contributing stakeholders, it is important to provide those stakeholders the ability to specify the extent to which their data is visible to others. Once data are in the PCD-WCTS, a second iPad app function permits data-owner users who have stored data in PCD-WCTS to select what data they wish to share and with whom. In this way, a supply-chain participant can assign viewing rights for specific data pieces to specific individuals. This precludes un-authorized viewing, and allows data owners (those who put the data in) complete control over their information. Only firms who have entered information into the system, or those they have pre-authorized—such as other producers, feedlots, and processors—can access that information. The PCD-WCTS has standard and user-defined data-sharing templates. The templates provide the user the ability to define the specific data fields within animal records that would be shared giving users the ability to more rapidly share specific data for specific animals to other specific users. For a detailed explanation and illustration of this feature, see Adam et al. 2015.

Data Immutability

It is critical that the validity of data stored in any system be trusted by its stakeholders. Thus, one of the primary concepts built into PCD-WCTS is that of data immutability. This simply means that existing data values become fixed and unchangeable after certain events take place, such as transferring an animal from one owner to another. As an analogy, consider a contract between two parties. Once the contract has been entered, it generally is not modified; instead, changes or corrections are entered as addenda—or attachments—to the original document. For example, assume that after an animal has been transferred from a producer to a feed lot, it is discovered that the original birthdate of the animal entered into the system is incorrect. Rather than changing the birthdate (which now is immutable because of the transfer), a correction record will be attached to the original record correcting the incorrect information. Thus, both the original, incorrect data as well as the corrected data are available, giving a more complete, trustworthy history of the animal.

Security and the PCD-WCTS Architecture

One of the key decisions to be made in implementing a whole-chain traceability system is the kind of database architecture used. The choice reflects a tradeoff between robustness of the traceability system and perceived independence of each firm (which could affect participation). There are currently at least two possible kinds of architectures for the WCTS database for food; each has committed advocates. One approach is a distributed peer-to-peer model where the database is distributed across multiple sites (Özsu et al. 2011). Each site is, for the most part, self-sustained, managing its own security such as Domain Authentication Services and Application security as well as applications. Each site also manages its own backups, controls its own Internet access, and hosts its own shared files. This is similar to the architecture described by and anticipated for use by the Global Food Traceability Center (GFTC 2014, 6).

A second approach is a centralized (Kroenke et al. 2014) or silo, model. In this approach, all the data is stored in centralized servers. Security, backups, Internet access, shared files, applications are all managed locally at one location. In this architecture, if a specific data request is made and data-owner grants the request, the data would be released from the centralized servers.

Each approach has advantages and disadvantages. An advantage of the distributed approach is that it is more scalable. It also may be perceived as allowing each participating firm more independence, perhaps encouraging greater participation. However, there are disadvantages. In the distributed model there are no uniform system-wide security or backup policies. Each site decides its own security and backup policies. The distributed architecture requires inter-site communications to trace a particular product, so the weakest link in the chain determines the security of the whole system. Under the stress of a product recall, an outage at one firm could break the traceability chain. If a traceback is needed because of a food safety event, gaining access to the needed information depends on each site having its data accessible; the traceback will be only as fast as the slowest link.

In a centralized model, there is separation of data for management and security reasons. In contrast to a distributed model, security, backup and other controls are managed centrally. A disadvantage of a centralized system is that if an attacker breaks or penetrates the security of a centralized silo, he may be able to compromise the whole system. Similarly, a natural disaster could cripple the data server, but this could be mitigated using distributed backup centers. However, there are several important advantages. It is easier in a centralized system to ensure that the database server is stored in a secure server room. Uniform security and backup policies that take into consideration all the stakeholders' requirements can be more easily implemented since all data is stored in secured data centers. There is also less administrative overhead since there is one set of policies. There is full control over potential risk areas such as internet access and there is no need for inter-site communications.

The PCD-WCTS is designed using centralized architecture. Thus, the system incorporates Carestream's (2011) four components of data security: availability, confidentiality, integrity, and tracking ability. Although the system is currently at a pilot scale, preliminary development planning conducted as part of the USDA-NIFSI project developing this system suggests that a scaled-up system could be fully funded with a charge to supply chain participants of 1/2¢ per transaction. The following discussion draws examples from beef supply chains to highlight benefits of using the PCD-WCTS in a fragmented supply chain.

Benefits of PCD-WCTS in a Fragmented Supply Chain

Animal Disease Traceability

USDA-APHIS notes on its website that:

> "Animal disease traceability, or knowing where diseased and at-risk animals are, where they've been, and when, is very important to ensure a rapid response when animal disease events take place. An efficient and accurate animal disease traceability system helps reduce the number of animals involved in an investigation, reduces the time needed to respond, and decreases the cost to producers and the government."

Widespread adoption of a PCD-WCTS in the beef supply chain could greatly expedite a USDA-APHIS investigation, since data observations in the PCD-WCTS are associated with specific animals or products. Because the majority of the data observations are expected to be uploaded and stored in the centralized server, these observations could be analyzed rapidly (assuming the data-owner has given the agency access to the data) to provide timely food safety and animal disease results and projections. Since those who put information into PCD-WCTS own and control it, USDA and FDA are viewed as potential users of the data, much as other participants in the supply chain. A prior arrangement could be made in which producers choose to grant them assess through a template that specifies release of very basic information such as the animal id, time, and location to the USDA on condition that an animal disease event is declared.

Value Added

More and more companies have realized the benefit of using a traceability system to improve supply chain management or to transfer credence attributes along the supply chain. Because PCD-WCTS permits users to control their own data, they have the ability as well as the incentive to use it for a much greater range of value-added purposes.

Value Added to Consumers

In addition to the many supply-side benefits of WCTS use, traceability can be viewed as an assurance of quality and/or safety – a value-added factor in the eyes of consumers. The rise in demand for short supply chain (e.g. local foods) offerings and the successes of MarketMaker® and the Top 10 Produce/Our Locale "know your farmer, know your food" traceability system are anecdotal examples of the value consumers attribute to a food product's traceability for origin or protocol verification.

Deselnicu et al. (2013) confirmed the value of traceability to origin in a meta-analysis of geography-based food valuation studies. The authors concluded that premiums for origin-based labels tend to be greatest in low/no-processed foods with distinct geographic indications, even after accounting for differences across food characteristics and trademarks/brands. Lim et al. (2013), using various models, determined that consumers were willing to pay a premium of $5.85/lb. for traceable beef steaks.

Traceability as a value-added measure of quality assurance and food safety can be directly tied to marketing efforts. Yeung and Lee (2012) demonstrated how marketers can use traceability, quality assurance, and independent organization endorsements as marketing strategies to improve consumers' purchase intentions when food safety concerns exist. The authors found that food industry members can benefit from using trace-based information to assuage consumer anxiety in times of food safety uncertainty.

As an example of value-added to consumers, genetic information is one of many attributes that can be transferred along a chain. DeVuyst et al. (2007) and Weaber and Lusk (2010) noted that certain genetic characteristics have a higher likelihood of resulting in more tender beef cuts. Lusk et al. (2001) found that consumers were willing to pay a premium averaging $1.23/lb. for a tender steak versus a tough one ($1.84/lb. if they were given more information about the steak's tenderness), with 20% willing to pay $2.67/lb. or more.

However, in a typical fragmented supply chain without traceability, it is difficult to convert consumer willingness to pay for desired characteristics into compensation to producers of those characteristics, because supply chains are complex, with many transactions involving products with multiple quality characteristics. Thus, in the beef supply chain, even though consumers are willing to pay more for it, producers receive very little price incentive to provide animals that produce more tender meat. If producers could receive a price incentive large enough to cover additional production costs, they could profitably increase value added to consumers. The PCD-WCTS permits processors to direct premiums as incentives to those producers who provide the increased value, without diluting those incentives by dispersing them through the entire supply chain. The potential value added compares favorably to the estimated ½ cent-per-transaction cost of running the traceability system, noted above.

In this vein, Ge (2014) showed that both producers and processors would benefit economically if they used a whole-chain traceability system in the beef supply chain to provide more tender beef, as one example. If a WCTS were in place that could transfer incentives from processors to cow/calf producers directly to produce animals with genetics favoring more tender meat, results indicate that producers could increase profit per head by $45, considerably more than the approximately $6/head cost of implementing traceability. The net benefits would be higher for producers taking advantage of more than one value-added opportunity (such as improved location of injection sites or providing production information to livestock feed companies). These benefits would depend on an effective system in which information and financial remuneration can be transferred directly from the beneficiaries at one stage to those providing the value, often several stages up the supply chain, rather than through each stage sequentially. Individual producers would not necessarily benefit from adding value to their products unless such a mechanism were instituted.

Value Added to Other Supply Chain Participants (Supply Chain Management)

WCTS can be an especially important tool for applying “precision agriculture” to animal agriculture. The technology allows for data on carcass and growth performance of progeny of individual cows to flow back upstream, allowing for improved management of those cows. Analyzing the collection of *big data* will improve confidence in (EPDs) for important traits. For example, by including information about sires in the data flow of commercial cattle, breed associations could more quickly isolate genetics with superior feed efficiency or tenderness, while assisting cattle feeders in determining optimum time on feed.

Cattle Feeding Efficiency

Feeding cattle is one of the major activities of cattle production. The cost incurred for feeding cattle is the single largest variable cost (Sherman, Nkrumah, and Moore 2010). A traceability system can provide information to improve cattle feed efficiency, providing cost savings. Many feed efficiency genetic characteristics of cattle are moderately heritable (Herring 2003; Elzo et al. 2009). Thus, the cow/calf operator and seed stocker operator could produce cattle with higher feed efficiency through selection or other genetic related management activities. By using PCD-WCTS, this information could be transmitted through a traceability system, from those who provide the value directly to those who can benefit from it and in turn compensate the providers.

In addition to genetic information used to select particular animals and not others, a traceability system can help a feedlot operator optimize the feeding operation by allowing the operator to sort animals by particular characteristics related to feed efficiency, including genetic information. Or, vaccination records for each animal can prevent overmedication of individual animals, reducing costs and the potential for development of antibiotic resistance. In effect, as more information is provided, the more each animal can be treated as an individual and optimal care can be provided. This is especially the case for information that is not readily observable—such as vaccination history and weaning age and weight—as the cattle enter the feedlot but that could be transmitted through a traceability system much more quickly and less costly than with a paper-based system. The PCD-WCTS permits producers to provide this information directly to those who find it valuable, without sharing it with others in the supply chain.

Value Added - An Interface with MarketMaker®

One of the features of PCD-WCTS is its ability to interface with other systems. Even when producers have products with value-added characteristics, participating in a traceability system is not sufficient to give producers access to markets which value those characteristics. Farmers must be able to identify and make their products available to buyers who want value-added attributes. Building an interface between PCD-WCTS and MarketMaker® provides an opportunity especially for small and mid-sized farmers to expand into more differentiated, higher value markets. It would also allow farms and businesses to compete in markets demanding traceability and source verification.

MarketMaker® is a web-based platform that assembles, standardizes and geocodes information on farms and food related businesses in the US. It was initially developed by the University of Illinois as resource for the development of alternative food supply chains organized around marketable points of differentiation. Now supported by land grant universities and state departments of agriculture in more than twenty states, farms and business across the country provide profiles that can be mapped and queried by customers based on specific characteristics. This allows food buyers to identify potential regional and local sources of products with specific characteristics, and allows for more agile coordination of alternative supply chains.

MarketMaker® is currently developing a National Beef Portal to expand farmer/rancher profiles and search parameters to include all farm supplies, production, transportation, and marketing for all beef industry related categories. This would provide a delivery system for more sophisticated business and marketing tools, enhancing value-added capabilities.

Interfacing with PCD-WCTS would provide Portal users the ability to track individual animals through the supply chain, making animals with value-added characteristics visible to MarketMaker® users. For example, cattle feeders, local processors, and even beef marketing firms such as Certified Angus Beef (CAB) or US Premium Beef using MarketMaker® would benefit from using PCD-WCTS to track cattle that have not been implanted or been exposed to antibiotics, or that have the genetic potential to be high marbling. MarketMaker® facilitates matching supply chains for products with value-added characteristics with those desiring those characteristics, so it would help processors, restaurants, and other buyers locate cattle that meet their specifications, including source verification and management and production practices that are identified through PCD-WCTS.

The interface could expand beyond beef, into fruits and vegetables. The interface between PCD-WCTS and *Top 10*, which extends traceability in producer supply chains to the consumer, could be used to aggregate product among producers within the MarketMaker® website. This would provide small producers with the necessary scale as well as with the traceability they need to sell into larger wholesale and retail markets.

Remaining Issues and Challenges

Technology such as the PCD-WCTS can help resolve many of the issues that have hindered widespread adoption of a WCTS in the beef industry. The potential food safety and animal disease mitigation, as well as value added, benefits are large. However, several challenges remain.

Protection of Proprietary Information

Since one of beef producers' main concerns leading to abandonment of the NAIS was lack of maintaining confidentiality of proprietary information, a key feature of the PCD-WCTS is that those who input information control the release of that information. However, unless proper diligence is exercised in setting up the legal framework, it is conceivable that data put into the PCD-WCTS could be subject to Freedom of Information Act requests, or the state-level equivalents. This would discourage participation. While a decentralized architecture might make such litigation more difficult than in a centralized architecture (because of the greater number of potential defendants with a decentralized architecture), it is likely that the legal principles, and the need to address them, would be similar. Legal arrangements that can potentially resolve this issue must be investigated before an appropriate institution is selected to host the data servers and administer the system.

Although the system's key feature of allowing those who input information to selectively share that information should lead to greater producer participation, it is possible that the number of producers choosing to participate and share basic information will not be sufficient to adequately trace animal disease or food safety events. Further research is needed to determine factors necessary to achieve critical adoption and use rates, including determining optimal fees, incentives, and subsidies.

Risk and Liability Re-Allocation from Processors to Producers

Producers participating in a WCTS face an increased liability risk. If an animal disease or food safety event can be traced further up the supply chain to a producer or group of producers, rather than just to a processor, those producers will face increased liability risk. Producers likely have less ability to manage that risk than most processors. While the trace-back ability may increase overall food safety, the reallocation of risk toward producers is likely to dissuade them from participating in a WCTS. In order to lessen the costs of risk reallocation, an indemnification, or insurance, system may be needed.

Transition from Paper to Digital Records

Among the remaining challenges to the implementation of whole chain traceability for the purposes of food safety is the need to convince small producers and manufacturers to transition from handwritten data to digital records. This will require investment in information systems and solutions, including data analysis and training. As part of the process there must be better means to predict a problem before it happens, to become truly proactive rather than reactive. Partnerships could be created that facilitate the use of big data in food safety as well as food production, processing, and distribution. The most important motivator, though, is likely to be as producers and others in the supply chain begin to see that the benefits of both converting to digital records and participating in a WCTS. An interface with MarketMaker® could provide additional training opportunities for producers as well as increase their value-added capabilities.

Large Data Sets in Food Safety Analysis

Another challenge likely will be the cost of analyzing the big data sets related to foodborne illnesses. Armbruster and MacDonell (2014) doubt that agriculture and food industries will be amenable to sharing the cost of developing the specialized skills needed to take advantage of big data. This may lead to more consolidation in the supply chain, as when Monsanto acquired Climate Corporation so that they could have access to localized weather forecasts based on historical data which had been generated while developing insurance proposals to farmers for weather related catastrophes (Bennett 2014). Monsanto is therefore able to offer farmers methods to increase yields by precise timing of field treatments such as fertilization or pesticide applications (Armbruster and MacDonell 2014).

Final Comment

Whole-chain traceability systems can use the information gathered at each stage or node along a supply chain to improve food safety and supply chain management, limit the negative impacts of food safety and animal disease events, and create value-added opportunities for supply chain entities. Fragmented supply chains pose special challenges. Firms sharing proprietary information throughout the supply chain risk having others exploit that information. Moreover, they may not be rewarded for providing information that is valued by a firm several stages up or down the supply chain. A key feature of the technology described here—the ability by firms to selectively share specific data—resolves much of this disincentive for firms to participate in whole-chain traceability. While the remaining institutional challenges are significant, the benefits to society, consumers, and businesses from widespread adoption of whole-chain traceability systems are potentially large.

References

Adam, B. D., M. Buser, B. Mayfield, J. Thomas, C. A. O'Bryan, and P. Crandall. 2015. Computer systems for whole-chain traceability in beef production systems. In *Food Safety: Emerging Issues, Technologies and Systems*. Edited by S.C. Ricke, J.R. Donaldson, and C.A. Phillips. Chapter 2: 9–16 Oxford, UK: Academic Press, Elsevier, Inc.

Angulo, A.M., and J.M. Gil. 2007. Risk perception and consumer willingness to pay for certified beef in Spain. *Food Quality and Preference* 18:1106–1117.

APHIS-USDA. 2009. Overview Report of the Benefit-Cost Analysis of the National Animal Identification System. April (slightly revised). https://www.aphis.usda.gov/traceability/downloads/Benefit_Cost_Analysis.pdf. [accessed February 2016].

Armbruster, W.J., M.M. MacDonell. 2014. Informatics to support international food safety. Proceedings of the 28th EnviroInfo 2014 Conference, Oldenburg, Germany September 10-12, 2014. http://enviroinfo.eu/sites/default/files/pdfs/vol8514/0127.pdf [accessed October 12, 2015].

Bennett, D. 2014. Inside Monsanto, America's third-most-hated company. *Bloomberg BusinessWeek-Technology*. http://www.bloomberg.com/news/articles/2014-07-03/gmo-factory-monsantos-high-tech-plans-to-feed-the-world. [accessed October 12, 2015].

Beuchat, L.R. 2006. Vectors and conditions for preharvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. *British Food Journal* 108(1):38–53.

Bhatt, T., G Buckley, J. McEntire, P. Lothian, B. Sterling, and C. Hickey. 2013. Making Traceability Work across the Entire Food Chain. *Journal of Food Science* 78(2):B21–B27.

Bitsch, V., N. Kokovic, and M. Rombach. 2014. Risk Communication and Market Effects during Foodborne Illnesses: A Comparative Case Study of Bacterial Outbreaks in the U.S. and in Germany. *International Food and Agribusiness Management Review* 17(3):97–114.

Blasi, D., G. Brester, C. Crosby, K. Dhuyvetter, J. Freeborn, D. Pendell, T. Schroeder, G. Smith, J. Stroade, and G. Tonsor. 2009. Benefit-Cost Analysis of the National Animal Identification System. Final Report submitted to USDA-APHIS on January 14. https://www.aphis.usda.gov/traceability/downloads/Benefit_Cost_Analysis.pdf.

Bottemiller, H. 2012. More illnesses tied to XL Foods beef. http://www.foodsafetynews.com/2012/10/more-illnesses-tied-to-xl-foods-beef-recall-expands-to-hong-kong/#. Vs3hNeYTx8F [accessed February 24, 2016].

Butler, L.J., F. Haque, J.W. Oltjen, G. Caja, J. Evans, V. Velez, L. Bennett, and C. Li. 2008. Benefits and Costs of Implementing an Animal Identification and Traceability System in California –Beef, Dairy, Sheep and Goats. University of California Research Report.

Carestream Health. 2011. How to evaluate the data security capabilities of cloud-based services. White Paper. http://www.slideshare.net/Carestream/how-to-evaluate-the-data-security-capabilities-of-cloudbased-services.

CDC. 1993. Update: multistate outbreak of *Escherichia coli* O157:H7 infections from hamburgers - Western United States, 1992–1993. Morbidity and Mortality Weekly Report. 42: 258–263.

CDC. 2008. Outbreak of Salmonella serotype Saintpaul infections associated with multiple raw produce items—United States, 2008. MMWR 57: 929-934.

Coffey, B., J. Mintert, S. Fox, T. Schroeder, L. Valentin. 2005. The Economic Impact of BSE on the US Beef Industry: Product Value Losses, Regulatory Costs, and Consumer Reactions. Kansas State University Agricultural Experimental Station and Cooperative Extension. Serial No. MF-2678, April.

Crandall, P. G., C. O'Bryan, D. Babu, N. Jarvis, M. L. Davis, M. Buser, B. Adam, J. Marcy, and S. C. Ricke. 2013. Whole-chain traceability, is it possible to trace your hamburger to a particular steer, a U. S. perspective? *Meat Science*. 95(2):137–144.

den Bakker, H.C., M. W. Allard, D. Bopp, E.W. Brown, J. Fontana, Z. Iqbal, A. Kinney, R . Limberger, K. A. Musser, M. Shudt, E. Strain, M. Wiedmann, and W. J. Wolfgang. 2014. Rapid Whole-Genome Sequencing for Surveillance of *Salmonella enterica* Serovar Enteritidis. Emerging Infectious Diseases 20(8):1306–1314. doi:10.3201/eid2008.131399.

Deselnicu, O.C., M. Costanigro, D.M. Souza-Monteiro, and D. Thilmany McFadden. 2013. A Meta-Analysis of Geographical Indication Food Valuation Studies: What Drives the Premium for Origin-Based Labels? *Journal of Agricultural and Resource Economics* 38(2):204–219.

DeVuyst, E. A., J. R. Bullinger, M. L. Bauer, P. T. Berg, and D. M. Larson. 2007. An economic analysis of genetic information: Leptin genotyping in fed cattle. *Journal of Agricultural and Resource Economics* 32(2): 291–305.

Dickinson, D.L., and D. Bailey. 2005. Experimental Evidence on Willingness to Pay for Red Meat Traceability in the United States, Canada, the United Kingdom, and Japan. *Journal of Agricultural and Applied Economics* 37(3):537–548.

Dumitrescu, O., O. Dauwaldera, G. Linaa. 2011. Present and future automation in bacteriology. *Clinical Microbiology and Infection* 17(5): 649–650. doi: 10.1111/ j.1469-0691.2011.03511.

Elzo, M.A., D.G. Riley, G.R. Hansen, D.D. Johnson, R.O. Myer, S.W. Coleman, C.C. Chase, J.G. Wasdin, and J.D. Driver. 2009. Effect of Breed Composition on Phenotypic Residual Feed Intake and Growth in Angus, Brahman, and Crossbred Cattle. *Journal of Animal Science* 87(12):3877–3886.

FDA. 2011. Food Safety Modernization Act (FSMA). http://www.fda.gov/Food/foodSafety/FSMA/ucm247546.htm [accessed March 1, 2013].

Food Safety News. 2016. Court OKs $4 million class action settlement with XL Foods. http://www.foodsafetynews.com/2016/02/court-oks-4-million-class-action-settlement-with-xl-foods/#.Vs3uL-YTx8F. [accessed February, 2016].

Fremaux, B., C. Prigent-Combaret, C. Vernozy-Rozand. 2008. Long-term survival of Shiga toxin-producing *Escherichia coli* in cattle effluents and environment: an updated review. *Veterinary Microbiology* 132(1–2):1–18. doi: 10.1016/j.vetmic.2008.05.015.

Fritz, M., and G. Schiefer. 2009. Tracking, Tracing, and Business Process Interests in Food Commodities: A Multi-level Decision Complexity. *International Journal of Production Economics* 117(2):317–329.

Ge, Candi. 2014. The Value of a Whole-Chain Traceability System in Transmitting Genetic Information about Beef Tenderness. M.S. Thesis, Oklahoma State University.

Global Food Traceability Center (GFTC). 2014. Concept for an Interoperable Architecture for Seafood Traceability. Discussion Paper. October 30, 2014.

Goetz, G. 2012. USDA confirms recalled Canadian beef entered U.S. *Food Safety News* 21-September. http://www.foodsafetynews.com/2012/09/usda-confirms-recalled-canadian-beef-entered-us/#.Vs3cneYTx8E. [accessed February 24, 2016].

Golan, E., B. Krissoff, F. Kuchler, K. Nelson, G. Price, and L. Calvin. 2003. Traceability in the US Food Supply: Dead End or Superhighway? *Choices.* Second Quarter. (2 2003a):17–20.

Golan, E., B. Krissoff, F. Kuchler, L. Calvin, K. Nelson, and G. Price. 2004. Traceability in the U.S. Food Supply: Economic Theory and Industry Studies. U.S. Department of Agriculture-Economic Research Service, Agricultural Economic Report No. 830. http://www.ers.usda.gov/publications/aer-agricultural-economic-report/aer830.aspx [accessed October 2, 2015.]

Goldsmith, P., N. Turan, and H. Gow. 2003. Food Safety in the Meat Industry: A Regulatory Quagmire. *International Food and Agribusiness Management Review* 6(1):25–37.

Grein, T.W., K.B. Kamara, G. Rodier, A.J. Plant, P. Bovier, M.J. Ryan, T. Ohyama, and D. L. Heymann. 2000. Rumors of disease in the global village: outbreak verification. *Emerging Infectious Diseases* 6(2): 97–102.

Herring, W.O. 2003. Genetics of Feed Efficiency in Angus Cattle. University of Florida.

Heymann, D.L., and G. R. Rodier. 2001. Hot spots in a wired world: WHO surveillance of emerging and re-emerging infectious diseases. *Lancet Infectious Diseases* 1(5):345–353.

Hu, J., X. Zhang, L.M. Moga, M. Neculita. 2013. Modeling and implementation of the vegetable supply chain traceability system. *Food Control* 30(1): 341–353.

IFT. 2009. Institute of Food Technologists/Food and Drug Administration, Contract No. 223-04-2503, Task Order No. 6, Traceability (Product Tracing) in Food Systems, Technical Report, revised. Volume 1 of 2.

Inns, T., C. Lane, T. Peters, T. Dallman, C. Chatt, N. McFarland, P. Crook, T. Bishop, J. Edge, J. Hawker, R. Elson, K. Neal, G.K. Adak, P. Cleary. Outbreak Control Team. 2015. A multi-country *Salmonella* Enteritidis phage type 14b outbreak associated with eggs from a German producer: 'near real-time' application of whole genome sequencing and food chain investigations, United Kingdom, May to September 2014. *Eurosurveillance* 20(16): 15–22.

International Food Information Council (IFIC). 2010. 2010 Food & Health Survey: Consumer Attitudes Toward Food Safety, Nutrition, & Health. IFIC Foundation publication. http://www.foodinsight.org/2010_Food_Health_ Survey_ Consumer_ Attitudes_Toward_Food_Safety_Nutrition_Health#sthash.m2S53ubj.dpbs [accessed October 9, 2015.]

Johnson, J.Y.M., J. E. Thomas, T. A. Graham, I. Townshend, J. Byrne, L.B. Selinger, V.P. J. Gannon. 2003. Prevalence of Escherichia coli O157:H7 and Salmonella spp. in surface waters of southern Alberta and its relation to manure sources. *Canadian Journal of Microbiology* 49(5): 326–335.

Kim, H.M., M.S. Fox, M. Gruninger. 1995. An ontology of quality for enterprise modelling. http://www.eil.utoronto.ca/wp-content/uploads/enterprise-modelling/papers/Kim-WETICE95.pdf [accessed October 9, 2015].

Köser, C.U., M. J. Ellington, E. J. P. Cartwright, S. H. Gillespie, N.M. Brown, M. Farrington, M. T. G. Holden, G. Dougan, S. D. Bentley, J. Parkhill, S. J. Peacock 2012. Routine use of microbial whole genome sequencing in diagnostic and public health microbiology. *PLoS Pathogens* 8(8): e1002824. doi:10.1371/journal.ppat.1002824.

Kroenke, D. and D. Auer. 2014. Database processing – Fundamentals, Design and Implementation. 13th Edition. Upper Saddle River, NJ: Pearson Education, Inc.

Lee, J.Y., D.B. Han, R.M. Nayga, and S.S. Lim. 2011. Valuing traceability of imported beef in Korea: an experimental auction approach. *Australian Journal of Agricultural and Resource Economics* 55(3):360–373.

Lewis, R.J., A. Corriveau, and W.R. Usborne. 2013. Independent review of XL Foods Inc. beef recall 2012. http://www.foodsafety.gc.ca/english/xl_reprt-rapprte.asp. [accessed February 24, 2016].

Lim, K.H., W. Hu, L.J. Maynard, and E. Goddard. 2013. U.S. Consumers' Preference and Willingness to Pay for Country-of-Origin-Labeled Beef Steak and Food Safety Enhancements. *Canadian Journal of Agricultural Economics* 61(1):93–118.

Loureiro, M.L. and W.J. Umberger. 2007. A Choice Experiment Model for Beef: What US Consumer Responses tell us about Relative Preferences for Food Safety, Country-of-Origin Labeling and Traceability. *Food Policy* 32(4):496–514.

Lusk, J. L., J.A. Fox, T. C. Schroeder, J. Mintert, and M. Koohmaraie. 2001. In-store valuation of steak tenderness. *American Journal of Agricultural Economics* 83 (3) : 539–550.

McKean, J. D. 2001. The importance of traceability for public health and consumer protection. *Reviews in Science and Technology* 20(2):363–371.

Ng, Desmond, and Victoria Salin. 2012. An Institutional Approach to the Examination of Food Safety. *International Food and Agribusiness Management Review* 15(2):21–46.

Orsi, R.H., M.L. Borowsky, P. Lauer, S.K. Young, C. Nusbaum, J.E. Galagan, B.W. Birren, R.A. Ivy, Q. Sun, L.M. Graves, B. Swaminathan, M. Wiedmann. 2008. Short-term genome evolution of *Listeria monocytogenes* in a non-controlled environment. *BMC Genomics* 13(9):539. doi: 10.1186/1471-2164-9-539.

Ortega, Carlos, and Derrell S. Peel. The Mexican Animal Identification System: Current Situation, Problems, and Potential. *Journal of Agricultural and Applied Economics* 42(3):551–557.

Pouliot, S., and D.A. Sumner. 2008. Traceability, liability, and incentives for food safety and quality. *American Journal of Agricultural Economics*. 90(1):15–27. doi: 10.1111/j.1467-8276.2007.01061.x.

Özsu M. A., and Valduriez, P. 2011. *Principles of Distributed Databases.* Third Edition. New York: Springer. doi:10.1007/978-1-4419-8834-8.

Pendell, D. L., G. W. Brester, T. C. Schroeder, K. C. Dhuyvetter, and G. T. Tonsor. 2010. Animal Identification and Tracing in the United States. *American Journal of Agricultural Economics* 92(4): 927–940.

Resende-Filho, M.A., and B. L. Buhr. 2006. Economic Evidence of Willingness to Pay for the National Animal Identification in the U.S. Presented at International Association of Agricultural Economics. August, 12–18. Gold Coast, Australia.

Resende-Filho., M.A., and B.L. Buhr. 2008. A Principal-Agent Model for Evaluating the Economic Value of a Traceability System: A Case Study with Injection-Site Lesion Control in Fed Cattle. *American Journal of Agricultural Economics* 90 (4): 1091–1102. doi: 10.1111/j.1467-8276.2008.01150.x.

Scallan, E., R.M. Hoekstra, F.J. Angulo, R.V. Tauxe, M.A. Widdowson, S.L. Roy, J.L. Jones, P.M. Griffin. 2011. Foodborne Illness Acquired in the United States–Major Pathogens. *Emerging Infectious Diseases* 17(1): 7–15.

Schroeder, T., and G. Tonsor. 2012. International Cattle ID and Traceability: Competitive Implications for the U.S. *Food Policy* 37:31–40.

Seyoum, Bruk, Brian D. Adam, Candi Ge, and Eric A. Devuyst. 2013. The Value of Genetic Information in a Whole-Chain Traceability System for Beef. Paper presented at AAEA Annual Meeting in Washington, DC, August 4–6. http://purl.umn.edu/150458.

Sherman, E.L., J.D. Nkrumah, and S.S. Moore. 2010. Whole genome single nucleotide polymorphism associations with feed intake and feed efficiency in beef cattle. *Journal of Animal Science* 88(1):16–22.

Shinbaum, Samantha, Philip G. Crandall, and Corliss A. O'Bryan. 2016. Evaluating Your Obligations for Employee Training According to the Food Safety Modernization Act. *Food Control* 60: 12–17. doi:10.1016/j.foodcont.2015.07.014

Smyth, S., P.W.B. Phillips 2002. Product differentiation alternatives: identity preservation, segregation, and traceability. *AgBioForum* 5 (2):30–42. http://www.agbioforum.org/v5n2/v5n2a01-smyth.htm [accessed 08 October 2015].

Soeder, J. 1993. Anatomy of an avoidable tragedy. *Restaurant Hospitality* 77(3): 34.

Stasiewicz, M.J., H.F. Oliver, M. Wiedmann, and H. C. den Bakker. 2015. Whole-Genome Sequencing allows for improved identification of persistent Listeria monocytogenes in food-associated environments. *Applied and Environmental Microbiology* 81(17): 6024–6037. doi: 10.1128/AEM.01049-15.

Sterling, Brian, Martin Gooch, Benjamin Dent, Nicole Marenick, Alexander Miller and Gilbert Sylvia. 2015. Assessing the Value and Role of Seafood Traceability from an Entire Value-Chain Perspective. *Comprehensive Reviews in Food Science and Food Safety* 14(3):205–268.

Thakur, M. and C.R. Hurburgh. 2009. Framework for implementing traceability system in the bulk grain supply chain. *Journal of Food Engineering* 95 (4):617–626. doi:10.1016/i.jfoodeng2009.06.02 8.

Tonsor, G., and T. Schroeder. 2006. Livestock Identification. *Journal of International Food and Agribusiness Marketing* 18(4):103–118.

United States Department of Agriculture. Animal and Plant Health Inspection Service. 2015. Animal Disease Traceability. https://www.aphis.usda.gov/wps/portal/aphis/ourfocus/animalhealth?1dmy&urile=wcm%3apath%3a%2FAPHIS_Content_Library%2FSA_Our_Focus%2FSA_Animal_Health%2FSA_Traceability. [Accessed November 2, 2015].

United States Department of Agriculture. Animal and Plant Health Inspection Service. 2009. Overview Report of the Benefit-Cost Analysis of the National Animal Identification System. April (Slightly Revised). https://www.aphis.usda.gov/traceability/downloads/NAIS_overview_report.pdf

VCM International. 2014. Learning from Australia's Traceability and Meat Standards Program. http://vcm-international.com/wp-content/uploads/2014/09/Australias-Traceability-System-Case-Study-August-2014.pdf. [accessed May 13, 2016].

Weaber, R. L., and J. L. Lusk. 2010. The Economic Value of Improvements in Beef Tenderness by Genetic Marker Selection. *American Journal of Agricultural Economics* 92(5):1456-1471. doi: 10.1093/ajae/aaq062.

Wilson, K., and J.S. Brownstein. 2009. Early detection of disease outbreaks using the Internet *CMAJ* 180(8):8 829-831. doi:10.1503/cmaj.090215.

Wilson, K., B. von Tigerstrom, and C. McDougall. 2008. Protecting global health security through the International Health Regulations: requirements and challenges. *CMAJ* 179(1):44–48.

World Health Organization (WHO). 2015. http://www.who.int/foodsafety/areas_work/foodborne-diseases/en/ [accessed October 5, 2015].

Yeung, R. and W.M.S. Lee. 2012. Food Safety Concern: Incorporating Marketing Strategies into Consumer Risk Coping Framework. *British Food Journal* 114(1):40-53.

