Food Stability, Sensors and Value Chains: Issues and Challenges in Meat Traceability

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Abstract
The Australian ‘Pathways to Market’ project involves targeted investigation into how intelligent use of information can contribute to enhancing industry competitiveness, environmental sustainability and innovation in food value chains. It is focused on supporting premium food companies to adapt to, and capitalise on, the significant business opportunities that are already emerging from rapid market changes occurring in the Asia-Pacific region. The project’s starting point is that numerous challenges continue to be faced by food companies wishing to grasp these emerging opportunities. Australian food businesses increasingly need to be able to validate the quality of their production processes in real-time, respond effectively to new regulations and tougher quality and safety requirements, adapt to changing consumer preferences and prove their credentials in meeting higher environmental standards through sustainable business practice.

To investigate these challenges, one work-package in the project is conducting research into integrating food stability science, sensors and traceability to address value chain development in collaboration with a leading ‘premium beef’ company. Australia already has a number of systems in place for tracking and certifying the quality and safety of meat products and production processes. However, these processes continue to be heavily focused on the production end of the supply chain and there is limited integration of predictive models on sensor packaging to provide real-time monitoring, traceability and feedback along the entire meat supply chain. To date, investigation of how to collect, collate and re-purpose traceability data on beef livestock and meat as they are disaggregated post-slaughter and transformed into multiple individual consumer products remains limited. This paper describes the key issues and challenges to be addressed by this research work-package.

Keywords: Traceability, Sensors, Food Stability, Value Chains, Perishable Foods, Meat

1. Introduction
The Australian Research Council ‘Pathways to Market’ project is engaged in a holistic investigation of how smart collection, collation and re-purposing of data and information flows along food value chains, and how it can be optimised to generate increased value amongst supply chain participants. The project is differentiated from many other food supply chain research and development projects in that it extends its focus both further up, and further down, the food value chain. In food production, the project is investigating the role and value of all inputs and material flows including those pertaining to product provenance and the sustainability of environmental inputs/assets used. For consumers, the project is investigating fundamental questions about the impact on consumers’ preferences and buying patterns resulting from innovation in the availability, form and delivery channel used for presentation of aggregated information on product quality and provenance. This project also leverages an opportunity presented by Sense-T (Tasmania’s economy-wide intelligent sensor network <www.sense-T.org.au> as an infrastructural platform for exploring and integrating the data and information flows arising from the project.

The project aligns with key priorities of Australia’s Standing Council on Primary Industries (SCoPI) to develop a food and nutrition cross sector strategy (SCoPI, 2012) in (i) future food markets and industry competitiveness; (ii) food safety, integrity and traceability; (iii) climate change and resource efficiency-sustainability; and, (iv) technology translation and mitigation of adoption barriers. It also aims to capitalise on the reality that the Asia-Pacific region has a huge and rapidly expanding wealthy, mobile middle-class interested in purchasing high quality food products (Australia in the Asian Century, 2012), (Briggs, 2012). Despite the opportunities, numerous challenges including poor integration between information and material flows along food chains pose significant business risks and
costs to Australian food businesses (Dukovska-Popovska et al, 2010). To mitigate these risks and maximise the opportunities for food companies and other stakeholders along (especially) premium food supply chains, it is necessary to develop approaches to:

- Validate the quality of production (and processing and retail) processes in real-time;
- Respond effectively to changing standards, regulations and tougher quality and safety requirements;
- Capture and adapt to changing consumer preferences; and,
- Provide credentials to meet higher environmental standards and community expectations through sustainable business practice and social licence.

In investigating these issues and benefits, one work-package in the project is focused on demonstrating how insights on production and consumption generated through sensors, traceability systems and advanced modelling techniques can be implemented in smart applications to support value generation and sustainability in food value chains. Unsurprisingly, given the importance of global food supply chains, there is already a considerable body of research investigating how improved access to more and higher quality information in food supply chains can be used to enhance food safety, business decision-making, consumer choice (Bamgboje et al, 2014) and sustainable environmental management.

Noticeably however, most of this research has either been heavily focused on specific production processes, or limited to one-up/one-down traceability with immediate supply chain partners to primarily support compliance with changing food safety and quality standards and regulations (Dabbene et al, 2014; Bellon-Maurel et al, 2014). Despite large numbers of commercially available technologies for monitoring food safety and quality, reducing spoilage and supporting traceability, it is noticeable how few examples there are of systems integrating predictive food stability models with sensor packaging to provide real-time monitoring, traceability and feedback along entire perishable food chains (Donnelly et al, 2013; Iedermann et al, 2006; Kreyenschmidt et al, 2006; Mohebi et al, 2014). This gap is partly related to a lack of clarity around core concepts (Karlsen et al, 2013), disparities in the impact and perceived importance of key drivers amongst different stakeholders in food supply chains (Resende-Filho, 2012) and challenges arising due to supply chain fragmentation and the predominance of resource-poor small and medium sized enterprises (SMEs) (Bosona et al, 2013). But it is also partly because of the sheer complexity of the tasks involved in implementing and sustaining the generation of value along food value chains.

In this context, this paper describes key issues and challenges to be addressed in the research investigation into how best to collect, collate and re-purpose traceability data on beef livestock and meat. This investigation aims to understand and implement a system along an entire premium beef supply chain including post-slaughter as meat is disaggregated, packaged and transformed into multiple individual consumer products.

### 2. Supply Chains, Logistics and Value Generation

This investigation is focused on how best to integrate food stability science, sensors and traceability to optimise value and profitability with a premium beef supply chain. To approach this complex set of challenges, the research team has developed an extended beef supply chain model. This model conceptualises all key technical, logistical and informational elements (as well as how these inter-relate both within and between supply chain partners) as inputs necessary to optimise the visibility of material and information flows in the beef value chain.

This approach is itself, also contributing directly to the development of a generic domain reference model for the broader project on perishable food supply chains. It is anticipated that this domain reference model will contribute to analysis of the nature, type, location and role of required elements within any proposed food value chain. This reference model work is closely aligned to similar European efforts to improve the integration and visibility of information flows in perishable food chains amongst SMEs (e.g. eFoodChain1, Ferreira et al, 2012).

Optimizing business decisions within any food supply chain is highly challenging, especially when chains are long and involve large numbers of SME stakeholders. There are still few examples of the comprehensive and systematic integration of market-sensitive information into logistics management and strategic, tactical and operational knowledge; those that do exist are driven by multinational corporations2. For perishable foods, optimising the supply chain will directly impact on production (costs, profitability, resilience, sustainability) as well as logistics management and sustainability. It will also directly impact on consumption by value-adding (consumer interactions with, experience of and feedback on) products and information about provenance, safety and choice.

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1 http://www.efoodchain.eu/
2 Pharmaceutical Industry Supply Chain Initiative: http://www.pharmaceuticalsupplychain.org/
More fundamentally, all food supply chains rely on a range of ecosystem and biodiversity services, and these factors need also to be analysed and addressed by any proposed systems.

As highlighted above, there is already a considerable body of research relevant to this project. Since at least 2000, numerous businesses have been exploring methods for re-engineering their entire supply chains. For most, a key step has been recognition of the need for more integration was also acknowledged prior to the end of Australia’s most recent beef organisational structures and systems tend to be restricted to one-up/one-down interactions for regulatory compliance in relation to internally within individual businesses. There is still relatively limited integration along entire supply chains and current inter-organisational structures and systems tend to be restricted to one-up/one-down interactions for regulatory compliance in relation to meat safety and quality. The need for more integration was also acknowledged prior to the end of Australia’s most recent beef cooperative research centre. This CRC developed the beef profits partnership (BPP) including some resources and tools to stimulate meat safety and quality. The present situation within Australian red meat supply chains (consisting of the supply of beef, sheep and goats), presents significant opportunities for supply chain profitability to be achieved by more broadly integrating on-farm and off-farm logistics activities. Contemporary on-farm and off-farm activities tend to restrict the development of value and profitability to decisions made internally within individual businesses. There is still relatively limited integration along entire supply chains and current inter-organisational structures and systems tend to be restricted to one-up/one-down interactions for regulatory compliance in relation to meat safety and quality. The need for more integration was also acknowledged prior to the end of Australia’s most recent beef cooperative research centre. This CRC developed the beef profits partnership (BPP) including some resources and tools to stimulate businesses to think about how to forge profitable collaborations within the beef supply chain.

In this project, success will be measured in terms of the impact on all supply chain participants within the extended beef supply chain model, rather than in terms of profits at an individual stage or for an individual business (Chopra and Meindl, 2004).

3. Exploring Optimisation in Australian Red Meat Supply Chains

The present situation within Australian red meat supply chains (consisting of the supply of beef, sheep and goats), presents significant opportunities for supply chain profitability to be achieved by more broadly integrating on-farm and off-farm logistics activities. These types of supply chain profitability strategies shift the focus from individual businesses to analysis of how business relationships, cooperation and integration can be supported through technical, logistical and informational elements to generate value and sustainability along the chain.

In this context, it is useful to explore opportunities for optimisation within current value-adding approaches in Australian red meat supply chains. Activities on-farm are primarily focused on managing livestock production and assurance of livestock rearing practices using a range of farm tools, risk management protocols and quality control actions. The Livestock Production Assurance (LPA) Program, for example, is the supply chain’s on-farm food safety certification program, and it provides for quality assurance for such things as property risk assessments, safe and responsible meat treatment, stock foods, and preparation of livestock for despatch. Activities off-farm are primarily focused on adding value through quality assurance of meat products after initial livestock rearing. This variously involves activities that include: feedlots, transportation, saleyards and processing. For feedlots, the National Feedlot Accreditation Scheme is an assurance system that impacts on red meat quality and acceptability, animal welfare, environment and water. For transportation, the TruckCare program maintains standards for handling of livestock through all stages of the red meat market. This supports transportation assurance programs for livestock targeting critical control points along the chain and aims to ensure that livestock are transported professionally and that transport operations are audited. For saleyards, the National Saleyard Quality Assurance Program controls what happens during livestock procurement. Perhaps most importantly for meat processing, the Australian government legislation and standards from Australian Quarantine and Inspection Service (AQIS) is based on health certifications for microbial assessment, and monitoring at all meat processing plants. This approach aims to mitigate risks including those arising from bacterial contamination such as E. coli and Salmonella, and aims to ensure meat stability through micro-organism monitoring and residues survey.

While each of these on-farm and off-farm activities already contribute significant value in meat supply chains, they have tended to be implemented pragmatically as discrete and linear operations and/or processes within specific segments of the supply chain. However, over the last 10-15 years, considerable effort has been put into finding mechanisms to value-add along the chain through the development of a number of inter-organisational services. These services have aimed to broaden the potential to create whole-of-supply-chain profitability, and have been implemented through a range of strategies, initiatives, entities and technologies. These services include AusMeat, AusQual and are underpinned by technologies that include the National Livestock Identification System (NLIS).

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AusMeat\(^{11}\), for example, has developed a common language that describes red meat products while AusQual\(^{12}\) provides certification and attestation to various quality management systems (including ISO 9001:2008) and the Pasture Fed Cattle Assurance System (PCAS). These services are available to organisations both up and down the supply chain. This current level of integration has been achieved by the successful development and implementation of the NLIS\(^{13}\). Introduced in 1999, NLIS is a traceability system that manages information on livestock from their birth through to slaughter. It aims to support post-mortem traceability of cattle to mitigate risks arising from disease and food incidents. It was established for beef but has subsequently been expanded to other red meat (lamb, sheep and goats). It provides a system for biosecurity, meat safety, product integrity and market access, underpinned by State and Federal legislation and a centralised NLIS document database and standardised tracking and tracing technologies.

In exploring these existing services and systems for meat (and in particular beef) supply chains, it is clear that the NLIS and allied services provide very good coverage in certain parts of the supply chains, with a strong focus on production to slaughter and, within that primarily at key supply chain focal points for post-mortem traceability (i.e. limited use of real-time monitoring). From figure 1, it is possible to highlight that there has been limited exploration of the value of these services (or indeed user/consumer requirements) post secondary processing. It is also evident that there is limited feedback along the supply chain, and that to date the integration between material and information flows particularly in real-time remains problematic.

Applying value chain and supply chain profitability thinking to Australian premium red meat supply chains could offer a practicable way of supporting the development of solutions that integrate and extend initiatives delivering sustainability, value and profitability for supply chain participants. For example, sharing transportation to reduce waste by ensuring under-loaded trucks service multiple sale-yards, growers or processors could be one way of reducing transportation costs, environmental impacts and addressing key livestock handling requirements. Clearly however, this different approach to transportation in the supply chain would have to address concerns of companies such as some loss of operational control. It is acknowledged that supply chain sustainability is not without its own set of challenges and limitations (Srivastava 2007), such as overcoming limitations around sustainability measurement (i.e. extending measurement of sustainability along the chain) rather than limiting measures of success, e.g. profit or carbon reduction, to individual organisations. Examples of this shared measurement might include shared information systems, technologies or applications or agreed-upon metrics, e.g. joint carbon miles or joint carbon-footprints.

While historically it has been difficult to determine supply chain profitability, advances in the widespread availability of low-cost technologies, including sensors and tags allied with traceability systems, now make the application of supply chain sustainability and

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other whole of supply chain initiatives feasible. These will directly change the ways which premium red meat supply chain achieves greater profitability into the future

The next section discusses considerations around integrating food stability, sensors and traceability systems


Australia’s beef industry already has systems and technologies in operation for tracking and certifying the quality and safety of meat products and production processes. The project’s industry partner is already advanced in their use of many existing systems however challenges remain particularly post-processing. These challenges have become ever more important as the industry partner strengthens a business strategy that is already delivering a significant price premium from ‘never-ever’ style branding. This branding guarantees customers that the beef product contains no antibiotics or hormones, and that the beef herds from which it is produced have never been grain-fed or fattened in feed-lots. Increasingly guaranteeing and being able to verify to ever higher levels of accuracy and timeliness presents a key focus for the integration of food stability models and new/existing sensors into extended traceability systems. As is discussed below, with a myriad of available technologies, applications and services in the market-place a key challenge is one of choice aligned to evaluation of attributes including inter-operability, accuracy, scalability and robustness.

4.1 Meat Stability and Sensor Technologies

The stability of red meat quality and safety under various handling conditions is well advanced. For certain parameters, such as microbial growth, predictive models, including those produced via various MLA-funded projects are available (Kiermeier et al., 2013; Small et al., 2012) in addition to some which focus on specific input factors such as temperature (Raab et al, 2011). However, what is not known is how such models can be effectively integrated with supply chains sensors, as well as who values and benefits from model predictions of shelf-life and safety. In addition, the majority of models were developed under static laboratory conditions, and therefore their performance must be validated under dynamic conditions occurring in actual supply chains.

An excellent illustration of a highly valued supply chain model, is the MLA Refrigeration Index (RI), used by Australian beef exporters to predict the growth, if any, of E. coli on beef products during chilling operations prior to export. This approach increased the confidence of importers and drastically reduced production costs. A validation of the RI resulted in the Australian Quarantine Inspection Service (AQIS, 2001) adopting the model to evaluate the hygienic quality of red meat, thus producing greater flexibility in industry operations and the development of flexible and innovative approaches for chilling meat products. The Australian Centre for International Economics (CIE, 2006) evaluation of the benefits of predictive microbiology on costs (versus in the absence of predictive microbiology), determined that over a 30-year period, MLA’s investment increased the value of the Australian meat industry by $44 million, added $162 million to the GDP, and produced $71 million in benefits to consumers. Such positive outcomes confirm the potential of models and sensors in adding value over the entire spectra of a supply chain.

Addressing the challenge of how to further validate these food stability models along supply chains has contributed to increased interest in the development and use of a wide range of a different types of sensors both at fixed points along beef chains and also as embedded tags/sensors directly aligned to different beef products/packages post-processing. Recent reviews of both active and passive sensor technologies and package sensors have been completed by members of the project team (Mohebi et al, 2014; Fernandez-Piquer et al, 2014). These reviews highlight that some technologies available are very accurate but also expensive, time consuming and require expertise for their interpretation and use. Other systems are very cheap, easy to deploy, use and interpret but are prone to failure, are less accurate and have limited capacity, life-space and utility beyond specific features or functions. In essence, the challenge is choice – what criteria should be used to select them, how accurate are they, under what conditions, how inter-operable are the data produced and how can they contribute to value chain profitability and sustainability?

Despite more recent advances in lower cost integrated solutions that are extensible (e.g. shockwatch), there is as yet, no strong return-on-investment framework beyond individual company compliance with safety/quality regulations in their segment of the supply chain. Other factors including the complexity of legal liabilities and changing food safety requirements have contributed to slower adoption of these solutions in the production side of food chains (Mohebi et al, 2014). On the consumption side of the supply chain other factors including the dominance of supermarkets in food retail and resistance to greater information transparency for consumers by some agri-business lobbyists have also impaired the development of whole supply chain solutions (Barker, 2014, Mirowski et al (2014)
Capling & Ravenhill, 2011; Kearney, 2010). It is however, interesting to see note the rapid emergence of new retail/consumer patterns in the premium end of the food consumer market\textsuperscript{16,17}

In approaching these challenges, this project is in the process of developing an integrated sensor and traceability system reference model for the entire chain enabling individual organisations to make informed decisions about selection and adoption of technologies, systems and services that optimise value and resilience along the chain.

### 4.2 Traceability Systems

The selection and adoption of sensors for food stability is intimately related to the range of track and trace functions available technologies that are required within any supply chain (Jedermann et al, 2006). As outlined, this project has adopted an extended supply chain model that requires traceability to be re-defined holistically as involving both production and consumption. Based on the International Standards Organisation (ISO9001, 2000 Quality Management Systems) definition: Traceability can be simply described as: `The ability to trace the history, application or location of that which is under consideration’ with the additional qualification that in relation to product traceability there is a need for detail on ‘the origin of materials and parts, the processing history, and the distribution and location of the product after delivery.’

While the concept of traceability is straight-forward, the way it is defined in the literature displays a high degree of definitional ambiguity that continues to cause confusion. Given the focus on traceability systems and technologies it is useful to consider traceability in this project as fundamentally being about the collection, storage, management and dissemination of data and information associated with material (or virtual) products, production and consumption processes that allow for their identification, history and location to be tracked and traced in real-time or post-mortem.

Over the last two decades interest in traceability and advances in traceability technologies and systems has been primarily stimulated by factors related to ensuring food safety and quality and the sustainability of food production processes (Salampasis et al, 2012; Schwagele, 2005). From food scandals and concerns about GMO contamination through to changing consumer awareness of, and interest in food provenance, traceability requirements for food have been formally legislated, monitored and enforced widely around the world (<www.tracefood.org>)

Similar to the variety of sensors, existing systems and technologies for traceability vary in form, type and level of sophistication. From physical and paper-based, through digital/optical to chemical and genomic traceability technologies are used in a variety of ways, for a number of purposes at different points along supply chains. While a number of individual technologies can be identified, most traceability systems currently deployed are either, restricted to use of individual technologies in individual firms (primarily for inventory management) or, limited to ‘one-up/one-down’ parts of the food supply chain to support compliance with industry certification schemes and legal frameworks.

Alongside data standards, attributes/forms/associations for digital exchange and non-repudiation, the project will aim to address traceability and logistics from a number of different perspectives. Following Opara (2003) this whole of system supply chain perspective supports the identification of the following six dimensions of traceability:

1. Product traceability defines the physical location of a product at any stage in the supply chain.
2. Process traceability ascertains the type of activities that have affected the product during the growing and post-harvest operations (what, where and when).
3. Genetic traceability determines the genetic composition of the product and includes information on the type and origin (source, supplier).
4. Inputs traceability determines type and origin (source, supplier) of inputs, e.g. fertilizers, processes or inputs used for preservation or transformation of the raw materials into processed products.
5. Disease and pest traceability traces the epidemiology of microbiological hazards and pests that may contaminate products.
6. Measurement traceability relates individual measurement results through calibrations to reference standards and assures the quality of measurements by observing various factors which may have impact on results (such as environmental factors, operations etc.)


\textsuperscript{17} [http://www.wholefoodsmarket.com/](http://www.wholefoodsmarket.com/)
A 7th dimension that may be generated through innovation in this project relates to consumption traceability. The focus here is how aggregated real-time data, including that feedback voluntarily provided by consumers through their mobile devices about products, is used to generate and provide value. The impact and implications for transforming business practices and production processes will be investigated.

Beyond individual decisions about the type of traceability being focused on, the project also aims to determine the nature, type and granularity of the data/information attributes that are being recorded, manipulated and transmitted at different points in the supply chain and in response to the product and package transformations being supported. Following McEntire et al (2010) these attributes are being considered in four dimensions:

- **Breadth**: Number of attributes linked to each traceable entity;
- **Depth**: Distance along supply chain entity tracked;
- **Access**: Traceability data availability and comprehensibility along the supply chain;
- **Precision**: Accuracy and assurance of traceability data on entity tracked in terms of attributes.

Finally, the project will also give consideration to some of the challenges which are inherited when sensory information is associated with traceability information. For traceability systems such as those relying on Radio Frequency Identification (RFID) technologies, the challenges to be considered include entity provenance and authentication, information integrity and technologies security (Mirowski et al, 2009).

5. Next Steps

In trying to address the issues and challenges outlined above, this project is developing a conceptual framework that will produce a domain reference model that encapsulates the range of choices at different layers and in different segments of the chain (as well as the inter-relationships between them).

The basis of the engagement with the beef industry partner continues to strengthen and involves three-fold engagement in the manner this project work-package is using business and academic expertise in combination with new and existing systems and technologies, and modelling techniques. This engagement involves:

- **Direct engagement in problem-solving** around challenges/issues that have been identified but have yet to be addressed or assessed in detail. This is focused on demonstrations/trials/proof of concepts to mitigate risks and optimise value of implemented solutions;
- **Opportunity generation** to stimulate the development of new ideas/approaches to existing practices or the development of new practices. Again these can be tested/evaluated and validated prior to formal decision-making about their implementation in the business;
- **Disruption & Innovation** through expert analysis of the business, its environment and supply chain. It is anticipated that the research team will generate radical suggestions for alternative ways of using technology/systems to operate. This project opens up the opportunity to explore these new potentially disruptive systems at low risk.

For the Australian red meat supply chain, this may likely require multiple and integrated logistics activities not only across (meat) materials flows but also a variety of logistics activities including transportation, inventory management and warehousing. In achieving a much broader vision of supply chain profitability, the current research project is also intending to investigate a number of critical questions:

- **What are the service requirements for customer segments beyond a focal organisation’s immediate partners?**
- **How can operational integration be achieved amongst the various supply chain members?**
- **What is the supply chain structure that best minimizes costs and provides competitive levels of service for the whole supply chain?**
- **Are there opportunities to reduce transportation costs in both the short term and the long term by cooperating amongst heavy vehicle users?**
- **Can current inventory management procedures support more stringent customer service demands including eco-labelling, origin, provenance and nutrients?**
- **What information technology is required to gain maximum efficiency in logistics operations along the entire supply chain from variety development to consumption and back?**
• How should resources be organised to best achieve customer service and operating objectives along the entire supply chain?

6. Preliminary Conclusions: Research-in-Progress

This exciting project is still in its scoping phase and input from international collaborators is very welcome. More significantly, despite the availability of numerous technologies for supporting product identification and quality and safety certification, seamless interoperability to address transformation of supply chains involving SMEs is still very fragmented.

This project will address these complex issues and focus on how best to collect, collate and re-purpose traceability data on beef livestock and meat. The anticipated outcome is an integrated system along an entire premium beef supply chain including post-slaughter as meat is disaggregated, packaged and transformed into multiple individual consumer products.

7. References


