Final report

Global Review of Livestock Traceability Systems

Project code: V.ISC.2407 – Global Review of Livestock Traceability Systems

Prepared by: CORPORATE VALUE ASSOCIATES

Date published:19 November 2024

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

This project was undertaken to conduct a comprehensive global review of livestock traceability systems and identify potential technology advancements to be considered in the development of Integrity Systems Company's (ISC) next 5-year strategic plan. The research addressed the need for improved traceability in the face of evolving market demands and technological advancements. The project methodology involved an extensive literature review, global investigation of traceability systems across various industries, and a multi-criteria assessment of selected systems.

Key results include the identification of best-in-class traceability systems from countries such as Ireland, Japan, Uruguay, South Korea, and Zimbabwe, as well as innovative technologies like blockchain, GPS/IoT, and implantable devices. The research revealed that successful traceability systems often integrate multiple technologies, prioritise user-friendly interfaces, and provide benefits beyond basic traceability.

The project's findings offer valuable insights for the Australian red meat industry, including potential technologies and approaches to enhance the NLIS, strategies to increase supply chain efficiency, and methods to improve market access through advanced traceability. These results will support the industry in maintaining its global leadership in livestock traceability and meeting evolving regulatory and consumer demands.

Executive summary

Background

This research was undertaken to conduct a global investigation into traceability systems and approaches spanning livestock, other agricultural sectors, and relevant industries. The main questions addressed were:

1. What are the best-in-class traceability systems currently in use globally?
2. What new approaches and technologies have been implemented that give certain systems advantages?
3. How can these insights be applied to enhance Australian red meat livestock traceability?

The main target audience is the Australian red meat industry, including producers, processors, and regulators. The results will be used to inform areas for consideration in ISC's next 5-year strategic plan and broader traceability practices.

Objectives

The project aimed to:

- Conduct a literature review of previous MLA research on traceability systems
- Perform an extensive global investigation into traceability systems across various industries
- Assess the technical capabilities and overall success of these systems
- Identify systems and attributes applicable to enhancing Australian red meat livestock traceability

Methodology

1. Desktop research to develop a long list of potential systems to investigate
2. Shortlisting of priority technologies/systems for detailed review
3. Development of a multi-criteria assessment (MCA) framework
4. Detailed analysis of selected systems using the MCA framework
5. Synthesis of findings and development of recommendations

Results/key findings

1. Traceability systems in different countries are often designed with distinct primary purposes (e.g., product traceability, genetic evaluation)
2. Advanced technologies like Ultra High Frequency (UHF) RFID, blockchain, and DNA testing are being increasingly adopted
3. Successful systems often integrate multiple technologies and prioritise user-friendly interfaces
4. Many systems provide benefits beyond traceability, such as improved breeding programs and supply chain efficiency

Benefits to industry

The project's results will provide significant benefits to the Australian red meat industry by offering insights into best practices for enhancing traceability systems and identifying advancements in traceability technologies. Additionally, the findings will offer strategies to increase supply chain efficiency and market access through improved traceability methods.

Future research and recommendations

Recommendations for future research and development include:

1. Consider the combination of smart phone, GPS, UHF RFID and IoT technologies – working in combination to enhance the user experience of the traceability system; create more real-time location and traceability data; and address gaps in traceability knowledge.
2. Develop a comprehensive strategy to integrate valuable livestock data from third-party systems with the NLIS to enhance the overall traceability ecosystem beyond core NLIS functionality.
3. Researching the potential of digital ID systems to streamline documentation processes in the supply chain and further contemplate how blockchain is applicable to organising data and data access in the Australian system.
4. Consider how an increasing use of tissue sampling and genomic testing in Australia could integrate with or be accessible to traceability systems.

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1. Introduction

Australia positioned itself as a global leader in livestock traceability systems following the introduction of the NLIS in 1998 and launch of the LPA program in 2004.

The NLIS database has been in operation for more than 20 years, and it is nearing the end of its maintainable life. A replacement and enhancement project, the NLIS Database Uplift project, will modernise Australia's data capture, storage, and distribution system for livestock traceability.

Concurrently to the NLIS Database Uplift project, ISC is seeking to ensure that the broader global traceability context and state of the art of traceability technologies are considered when developing the next 5-year strategic plan.

Building on previous research into traceability systems and technologies, an extensive global investigation into traceability systems has been conducted which assessed the traceability systems and identified those that have applicability in Australia.

Current state of Australia's livestock traceability

The National Livestock Identification System (NLIS) is Australia's primary system for the identification and traceability of cattle, sheep, and goats. Operational for over two decades, the NLIS plays a crucial role in ensuring food safety, controlling disease outbreaks, promoting animal welfare, and meeting Australia's market access commitments. The system utilises visual or electronic (Low Frequency RFID) ear tags for livestock identification, with each physical location assigned a unique Property Identification Code (PIC) (Integrity Systems Company, 2024).

Central to the NLIS is a comprehensive database that records essential information for each animal, including its identification number, PIC, movement history (NVD record). The system mandates the application of NLIS approved tags to livestock, prior to the first movement off the property. In the event of tag loss in cattle, replacement orange tags are used (orange for cattle, or pink for sheep and goat). The tagging process adheres to specific timeframes as stipulated by regulations, with tags being destroyed after the processing of animals at abattoirs (Integrity Systems Company, 2024).

While the NLIS has been instrumental in maintaining Australia's livestock traceability, it faces several challenges. Lifetime traceability is compromised by voluntary tagging at birth and potential tag loss prior to leaving the PIC or during transit, which can lead to identification issues and subsequent value loss. While the uptake of electronic National Vendor Declarations (eNVD) is increasing, a significant portion of livestock data is still managed through paper-based forms. This dependence on manual processes increases the risk of transcription errors and hinders rapid traceability. Furthermore, the requirement for internet connectivity to update the system limits real-time data entry in areas with poor connectivity.

Data management within the NLIS presents additional challenges. These include ensuring the accuracy of manually entered data, such as NVD serial numbers, NLIS tag numbers and livestock volumes. The system would benefit from enhanced data validation and verification, potentially achieved through the implementation of IoT enabled data feeds and blockchain technology. Moreover, the valuable data collected is not fully leveraged for productivity or livestock performance improvements, and integration with data from other platforms is limited.

A significant limitation of the current NLIS is the lack of real-time, location-based tracking capabilities, where the National Traceability Standards and State/Territory legislation allow up to 2 days to require information. This makes it challenging to monitor livestock health, conditions, and movements as they occur, impacting industry management and profitability. The addition of real time tracking could add benefits to livestock producers, for example by reducing losses from theft, which a 2022 study by PWC estimated to be valued at an average $50 million annually (PwC, 2022). Real-time tracking would also form the basis of emergency disease monitoring, for example where cattle have recently moved locations or may even be in transit.

The NLIS also has unexplored potential for value-added benefits. Currently, product traceability is limited to batch level rather than individual animals, potentially restricting market access and premium pricing opportunities. The system's lack of international extension may limit Australia's ability to demonstrate its adherence to high standards in animal health, welfare, and sustainability on a global scale. Additionally, while various tests and/or processes (such as NVDs) are conducted, they are not seamlessly integrated into the traceability system, resulting in duplicated efforts, potential for data transcription error and missed opportunities for comprehensive data utilisation.

2. Objectives

There is a pressing need to ensure that the broader global traceability context and state of the art of traceability systems are considered when developing ISC's next 5 year strategic plan. This project aims to conduct a global investigation into traceability systems and technologies to understand new approaches to traceability in livestock and other industries.

In undertaking a global scan for traceability systems and approaches, this project aimed to meet the following objectives:

1. Conduct a literature review of previous MLA research projects on traceability systems and approaches.
2. Using the previous projects as a reference point, conduct an extensive global investigation into traceability systems and approaches spanning both livestock, other agricultural sectors as well as any other relevant industries. These should include private traceability systems that may be using block chain or artificial intelligence technology.
3. Specifically, investigate livestock traceability systems across the world and identify where new approaches and technologies have been put in place that give them an advantage.
4. Assess the technical capability and sophistication of these systems including how they utilise technology and innovative measures towards achieving lifetime traceability (e.g. sharing product claim credentials).
5. Identify and describe the context and drivers for the traceability system / approach and assess the systems' interoperability with other components of their supply chains, the competitive advantage the systems provide, and what the value proposition is of utilising these systems within their supply chains.
6. Assess overall success of these systems to manage compliance and the sharing of traceability data that is collected, how major breaches (if any) have been handled (including impacts to market access), how performance is measured at both a business/individual and industry level, and the subsequent reputation of the system's product.
7. Summarise the systems assessed including their key strengths and weaknesses to identify the systems/system attributes that could have applicability for enhancing Australian red meat livestock traceability.

3. Methodology

3.1 Overall project approach

Phase 1: Research Design

- Initiate a kick-off meeting to ensure alignment with the goals and objectives.
- Desktop review, leveraging Australian meat industry experts and CVA's global knowledge in agriculture and other relevant industries to develop a long list of potential systems to investigate.
- Refine the long list in consultation with MLA to identify priority tech/systems approaches for review.
- Design the multi-criteria assessment (MCA) by which to assess the features and benefits of different technologies and systems.
- Design the research timetable and questions.
- Agree on the approach and progress to desktop research phase as well as any additional requirements such as clarification meetings.

Deliverables

- Agreed list of approximately ten (10) priority technology/schemes to review.
- Agreed MCA.
- Agreed research approach and any stakeholder engagement to support desktop review.

Phase 2: Data Collection

- Collect data on key traceability system aspects, including technological infrastructure, data management protocols, regulatory compliance, and performance metrics.
- Data collection will include:
    - Review of existing MLA materials.
    - Desktop review of other published papers or reports as identified in phase one.
    - If required, interviews with systems proponents to clarify key points.
    - If required, talk to other experts in the key technology areas.

Deliverables

- Based on the agreed research design – conduct data gathering to complete a detailed MCA .

Phase 3: Assessment

- Evaluate identified systems' technical capabilities, sophistication, utilisation of innovative measures, and compatibility with traceability requirements – according to the MCA design.
- Link the comparison of the assessed systems to the red meat considerations in Australia, identifying their strengths, weaknesses, and potential applicability for enhancing the Australian red meat livestock traceability.

Deliverables

Comprehensive assessment of the traceability systems, including technical capability and sophistication assessment, overall success assessment.

Phase 4: Report & Communication

- Summarise the findings from the global scan and technical assessment, highlighting key insights and observations.
- Provide actionable recommendations based on the assessment findings, focusing on enhancing Australia's red meat integrity system.
- Develop a roadmap for implementing recommended strategies and technologies, considering short-term and long-term goals.

Deliverables

- A global scan report summarising extensive details on the traceability systems, comprehensive assessment of the traceability systems and recommendations.

3.2 Technology and system shortlisting process

Desktop research was conducted to develop a long list of systems and technologies that were potentially advanced and effective from a traceability perspective. This involved technologies / systems currently used in livestock traceability in Australia (e.g. smart GPS tags), examples of best practice traceability systems in other country markets, innovative traceability technologies in other industries (e.g. logistics cold chain supply management). Each system was described in terms of functionality, purpose and applicability to livestock traceability.

From this longlist, ten (10) systems were selected for detailed analysis based on a rapid evaluation of their capabilities.

The ten (10) shortlisted system / technologies fell into two broad categories: systems directly related to livestock traceability (e.g. best practice tracing systems in other countries), and systems from other industries (logistics, health care, mining/manufacturing, pharma, etc.).

3.3 System analysis using a multi-criteria assessment (MCA) framework

The identified technologies and systems were evaluated using a multi-criteria assessment (MCA) framework. This framework comprises of two components:

1. Scored criteria

The scored criteria assessment component involves ten (10) criteria which aim to evaluate the system / technology's performance in dimensions such as utility, extension capability, cost, effort to implement, etc.

Each system is given a score (from 1 to 3 in increments of 0.5). Each system will effectively receive a score out of 30 to assess its overall performance in the context of adding value to livestock traceability, particularly if adopted in the Australian context. The score is intended to be used as a guideline to compare and contrast these systems, and *not* as a definitive ranking.

The definitions of each of the scored criteria are described in Table 1.

Table 1 Scored multi-criteria assessment definitions

No.	Criteria	Definition
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?
5	Cost	Are costs related to a user accessing the system reasonable?
6	Effort	Is the contact time required of a user to engage the system reasonable?
7	Inter-operability	Is the system easily able to integrate data from or share data to other systems /platforms?
8	Validation	Is data added to the system self-reported, or third party assessed or validated?
9	Security	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?
10	Resilience	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?

2. Qualitative assessment

The qualitative assessment component aims to highlight the key advantages and disadvantages in each system, including any contextual insights that could not be explicitly captured as part of the scored criteria.

As part of the qualitative assessments, aspects such as funding model, assignment of identity, etc. are discussed if insightful.

4. Results

4.1 Overall assessment of technologies and systems

Based on the MCA assessment framework, the ten identified systems have been scored and ranked based on their performance or potential value-add from a livestock traceability perspective. The results are shown in Table 2.

Table 2 Scored MCA results for the selected traceability systems / technologies

	Utility	Extension	Technology	Adoptability	Cost	Effort	Interoperability	Validation	Security	Resilience	SCORE	RANK
Zimbabwe	3	3	2	2	3	2.5	3	3	3	3	27.5	A
Uruguay	3	3	2.5	3	3	2.5	3	2	2.5	3	27.5	
Blockchain	3	3	2	2.5	1	2	3	3	3	3	25.5	
Digital ID	1.5	2	3	2.5	2.5	3	3	3	2	2	24.5	B
GPS / IoT	3	2.5	2	2	0.5	2.5	3	2.5	2.5	2.5	23	
South Korea	3	3	2.5	2	2	1	2.5	2.5	2.5	2	23	C
Ireland	3	2	2	1.5	1	1.5	3	2.5	1.5	2.5	20.5	
Implantable Devices	3	2	2	2	1.5	0.5	3	2	2	2.5	20.5	
Japan	2.5	3	2.5	1	2.5	0.5	1.5	2.5	2.5	2	20.5	
DNA / Genomics	3	1	2	1.5	0.5	2	2	2.5	2.5	2.5	19.5	D

Based on the scored MCA framework, these systems were observed to belong to four broad categories:

RANK A:

- Examples of best-in-class systems currently used for livestock traceability purposes
- Provides benefits such as high level of Utility, Extension and Interoperability by allowing access to information regarding identity, movement, ownership transfer, herd history, etc.

RANK B:

- Promising technologies with interesting and innovative use cases to improve process efficiency (e.g. signing) and/or transparency (e.g. real-time location information during transport)
- Faces some barriers such as implementation cost

RANK C:

- Systems with advantages in areas such as product traceability, performance prediction, valuation etc.
- Provides lifetime livestock traceability as a secondary benefit

RANK D:

- Advanced and sophisticated technologies which provide value to the livestock industry, but in isolation does not directly provide value to livestock traceability

4.2 Detailed analysis of technologies and systems

4.2.1 Ireland: National Genotyping Programme

System overview

Ireland's livestock traceability system is delivered by the Irish Cattle Breeding Federation (ICBF). A key component of this system is the National Genotyping Programme (NGP), a collaborative initiative involving DNA testing and registration of cattle at birth. The NGP aims to achieve a fully genotyped national herd in Ireland, with approximately 2 million calf births registered annually since the program's launch (ICBF, 2024).

The program is scheduled to run initially for a 5-year period, starting in 2023. It is mandated that during this time, all newborn calves are to be genotyped at birth until 2027 (ICBF, 2024). Prior to this genotyping mandate, only 6% of the national dairy herd was genotyped (ICBF, 2024). This initiative is part of a broader traceability and breeding improvement strategy for Irish cattle, building upon existing systems like the Bovine Viral Diarrhea (BVD) testing program. The NGP incorporates DNA testing to enhance traceability, parentage verification, genomic EuroStar figures, Commercial Beef Value, and overall genetic improvement efforts.

In addition to the NGP, the ICBF provides the industry with numerous evaluation tools, including EuroStar, Dairy Beef Index, and Meat Eating Quality assessments. Beef and dairy farmers also benefit from HerdPlus, a paid data access portal that offers reports and insights on breeding information, performance data, and pedigree information (ICBF, 2024).

Cost structure

The National Genotyping Programme (NGP) operates on a cost-sharing model involving three main partners: the Department of Agriculture, Food & the Marine, the Dairy and Beef Industry (through DII and MII), and participating farmers. The total cost of €18 per genotype is equally divided among these partners.

Farmers also directly contribute approximately €6 per calf for genotyping, which includes €4 for the test itself and additional costs for specialised tags and postage. To encourage initial participation, the genotyping cost was waived for farmers during the program's first year of implementation (ICBF, 2024).

In addition to these direct costs, the system requires farmers to have an annual membership with either HerdPlus or the Suckler Cow Efficiency Program (SCEP). HerdPlus, ICBF's subscription service, provides herd-owners with performance data to help increase on-farm profit. The SCEP is a national program aimed at producing more carbon-efficient herds in Ireland, focusing on improving the genetic quality of the Irish suckler herd and reducing greenhouse gas intensity in beef production. The membership fee structure for these programs includes an annual base fee of €100 plus 50 cents for every dairy cow that calved in the previous year. This fee grants access to valuable tools and data that support informed breeding decisions and herd management practices (ICBF, 2024).

By combining genotyping with comprehensive data analysis and management tools, the NGP and associated programs aim to drive genetic improvement, enhance farm profitability, and contribute to Ireland's agricultural sustainability goals.

Main benefits provided

Early parentage verification:

- Genotyping calves at birth aims to reduce breeding record errors (15% prior to the NGP program inception) (Agriland, 2020)
- This ensures data accuracy and eliminates paperwork required to correct errors prior to animal registration

Enhanced national breeding indexes:

- Animals sampled at birth will receive genomic evaluations at the earliest possible opportunity, increasing the reliability of their Eurostar figures well before they are selected/sold for breeding and confirming their eligibility for SCEP
- As of 2023, there were over 79 marts throughout the country that are displaying Euro-Star and EBI figures on their mart boards. These provide real-time information on animals for sale thus allowing farmers ringside in marts to view the ICBF Euro-Star ratings for beef breeding stock and also EBIs for dairy stock (ICBF, 2023)

Transparency favouring export markets:

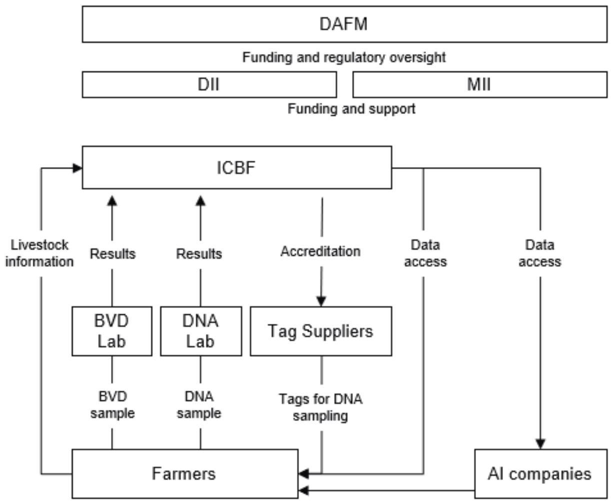
- Commercial Beef Value (CBV) displayed for genotyped cattle in marts, their information can be displayed on mart screens
- Genotyping creates DNA-based identification for the animal, not just based on physical tag, although it is not directly intended for traceability purposes

Improved breeding selection:

- Potential for improved sustainability through breeding for reduced methane emissions
- Animals can be identified as carriers of major genes (e.g. myostatin) and genetic diseases
- Ability to trace back ID of cows with high somatic cell count (SCC) from a single bulk milk sample

Stakeholder roles and responsibilities

Figure 1 Stakeholders involved in Ireland's livestock traceability system



Department of Agriculture, Food & the Marine (DAFM):

- Provides funding and regulatory oversightIrish Cattle Breeding Federation (ICBF):
- Responsible for overseeing the program, storing and maintaining database
- The ICBF receives lab results and incorporate it into the animal's genetic index (Euro-Star/EBI)

Dairy Industry Ireland (DII), Meat Industry Ireland (MII):

- Industry partners providing funding and support

Tag Suppliers

- Provide specialised double-tissue tags for DNA sampling
- Main tag supplies include Agritags, Cormac Tagging, Datamars, Mullinahone Co-op – all are required to be accredited by the ICBF

DNA/Genotyping Laboratory:

- Performs genotyping on DNA samples and sends results to ICBF for processing and storage
- All tests are provided by Weatherbys

Farmers:

- Responsible for collecting DNA sample and tagging livestock with a legal requirement to submit registration within 27 days from the birth of a calf

- Leverages data from ICBF for numerous purposes (e.g. traceability, performance, parentage, etc.)

AI (artificial insemination) Companies:

- Companies with farmers authorisation can receive parental average EBI of the calf as early indication of its potential (8-12 days after DNA sampling)
- Once genomic EBI is calculated for the calf (day 16-21) in the next bi-weekly evaluation, the result is made available for both farmer and the authorised AI company (ICBF, 2024)

Multi-criteria assessment

Table 3 Scored multi-criteria assessment result – Ireland

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The NGP generates outputs with value beyond traceability/biosecurity. It provides data for animal welfare, farm practices, and has potential for carbon accounting (through breeding for reduced methane emissions). It also enhances breeding decisions and market transparency. Genetic traceability (i.e. parentage confirmation) is the focus, rather than physical location traceability.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	HM	2	The system is specifically designed for and already applicable to livestock in Ireland, covering both dairy and beef cattle. However, the main purpose is in genetic evaluation, not specifically for traceability.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	M	2	While the technology is readily accessible to users in the Irish context, it requires specific equipment (double tissue tags), relies on internet access for registration and accessing performance insights (e.g., through HerdPlus), and needs a lab infrastructure capable of processing high volumes of DNA samples, which might not be readily accessible to users in the Australian context.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	1.5	The Irish system requires changes to existing practices and additional steps in the calf registration process. However, it's been designed to integrate with existing workflows. The driver for adoption would be Australia's demand for valuation of the entire national herd, rather than directly improving the current traceability system.
5	Cost	Are costs related to a user accessing the system reasonable?	L	1	While the cost is subsidised and shared between stakeholders, it does represent an increased expense for farmers compared to previous systems. An additional cost hurdle is the paid membership to access the system and performance reports and insights (e.g. HerdPlus).
6	Effort	Is the contact time required of a user to engage the system reasonable?	M	1.5	By sampling animals at birth, farmers eliminate the need for button tags or hair cards, unless a sample is identified as low quality. Despite later automation and display of results on the platform, farmers must send samples to labs within four

					weeks (at least twice per week during peak calving) and register calf details on AgFood Website.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The system integrates well with existing platforms (Agfood.ie, farm software packages) and can share data with various stakeholders (DAFM, AI companies, marts). Performance data are collected and insights provided via platforms such as HerdPlus.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	2.5	Animal performance data is validated through DNA, which provides a high level of accuracy for parentage and genetic information. During the sampling process, manually reported data (e.g. animal's parent, sex, etc.) are cross checked against DNA results, ensuring minimal reporting error.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	M	1.5	While the system handles sensitive data, there are some measures in place to protect it. Farmers can control access to their data (e.g. granting access to AI companies). The system utilises a centralised model where all data are managed and protected by the ICBF.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	2.5	The system appears to have robust mechanisms in place. It includes automated error detection and correction (e.g., for parentage), regular updates of genomic evaluations, and multiple access points (web, app) suggesting redundancy in the system.

Qualitative assessment

Advantages:

1. Identity designation is assigned to the animal based on genotyping result, rather than relying on manual tracking for a tag / ID number. This enhances the ability to provide lifetime traceability, even in the event of tag loss or damage. The average laboratory turnaround time for DNA sample processing is 4 days and the entire process including delivery of samples takes 10-12 days. (ICBF, 2022)
2. Resilience against reporting error: tagging calves at birth and performing genotyping before issuing animal passport ensures information is corrected (e.g. parentage, sex) before it is recorded. This removes paperwork and effort in correcting mis-reported information
3. Cost sharing model to minimise burden on farmers: this model lowers the cost of participation for farmers by distributing expenses between the government and the industry
4. Platform for mass usage: a centralised platform and online application facilitate widespread use and accessibility, making it easier for farmers to input and access data related to livestock genotyping and traceability. Services such as HerdPlus provide informative performance reports and dashboards to maximise insights gained from genotyping data
5. Transparency and trust through DNA validation: the use of DNA validation enhances transparency and builds trust among stakeholders by providing a verifiable record of genetic information about livestock, which is crucial for both valuation and traceability.
6. Integration of carbon accounting: there is a potential for integrating carbon accounting into the system, which can help in tracking and managing the environmental impact of livestock farming, aligning with sustainability goals.

Disadvantages:

1. High costs and coordination needed: implementing this system in Australia would be costly and requires extensive coordination and support from the government, industry, and farmers. The system is valuable for premium breeds, such as Angus, where the value added by traceability and genotyping justifies the additional expense.
2. Connectivity and double-tissue tags are required. Successful implementation depends on reliable internet access and the use of double tag technology, which might be challenging in remote or less technologically developed farming areas. RFID tags are not implemented to automate ID input into systems
3. Emphasis on valuation over physical traceability: genotyping is commonly done for valuation purposes as the primary driver, with traceability being only a secondary benefit. This focus can limit the broader adoption of the system for traceability alone, as the added cost is justified mainly by the increased value of premium livestock. Physical traceability is implied through tracing parentage and recorded farm information.

4.2.2 Japan - Japan Livestock Traceability System (JLTS)

System overview

Japan's livestock traceability system, known as the Japan Livestock Traceability System (JLTS), enables the traceability of its 2.69M head beef herd and was established in 2003 by the Ministry of Agriculture, Forestry and Fisheries (MAFF, USDA 2023). This system was formalised under the "Law for Special Measures Concerning the Management and Relay of Information for Individual Identification of Cattle," enacted in response to Japan's first confirmed case of Bovine Spongiform Encephalopathy (BSE) in 2001 (Ministry of Agriculture, Forestry and Fisheries, 2007).

The JLTS incorporates several key features to ensure comprehensive cattle traceability. At its core is the unique ten-digit Individual Identification Number (IIN) assigned to each animal, enabling precise tracking throughout its life. This system is mandated for all domestically raised cattle, ensuring universal coverage across Japan's beef industry. Within this system, Wagyu cattle require additional pedigree documentation to verify their prestigious lineage. In certain regions, such as Miyazaki Prefecture, the traceability measures are even more stringent, with muzzle prints being taken and transmitted along the supply chain to the point of sale, providing an extra layer of verification for these highly valued animals.

Cost structure

The Japanese government, through the Livestock Improvement Agency, provides ear tags free of charge as part of a subsidy program to promote livestock production. The costs of the traceability system are partially covered by government initiatives such as the Comprehensive Livestock Promotion measure project. However, industry organisations and producers are required to share in the expenses related to ear tags, reporting, and system maintenance. For the Wagyu registration system, which is separate but related to the general traceability system, additional fees are charged for calf registration inspections. This funding model ensures that the costs are distributed between governmental support for initial system setup and ongoing contributions, whilst minimizing burden on farmers (Ministry of Agriculture, Forestry and Fisheries, 2003).

Main benefits provided

Birth-to-plate traceability

- By law, identification numbers are assigned to the animal, its carcase and down to the individual cuts of dressed meat along the supply chain.
- Consumers and other industry stakeholders can use the system stored information to verify the identity of an animal, along with DOB, gender, breed and movement history. Other information that the producer must disclose includes (NLBC):
    - dam identification number,
    - location of the rearing facility (name of prefecture),
    - Dates of start and end date of rearing at the rearing facility
    - Date of slaughter, death or export
    - Type of cattle
    - For imported cattle - the name of the country of importation and the date of importation
    - Name and location of the slaughterhouse
    - For exported cattle - name of the country of exportation

- Other items that the system accepts which are optional to be disclosed include:
    - Name of administrator
    - Name of importer
    - Name of slaughterer
    - Name of exporter
    - Location of rearing facility (excluding prefecture)

Quality control

- Some Wagyu producers go the extra mile and have veterinarians perform daily health checks. The results and growth data are linked to the cattle's identification number, ensuring comprehensive care and quality control.

Fraud prevention

- Wagyu is a premium product, and as such relies on this system as a safeguard to prevent imitation Wagyu from infiltrating the market (Wagyu Farms Of Japan, 2024)
- DNA samples are extracted from all carcases and selected meat products. These are stored in a Livestock Improvement Association of Japan (LIAJ) and analysed to confirm authenticity between pre and post meat work products, by comparing them with the ones collected from retailers and caterers
- Muzzle prints are provided as part of certificate of authenticity. However, there does not appear to be a means through which the print can be used to validate animal information (NCBI, 2022)

Valuation

- Meat grading results is provided back to the producer at an individual animal level. Producers can learn the points of improvement from grading results. The better cows and bulls are selected for the better breeding, and the management is also improved by choosing the better blend of feed.
- For Wagyu breed improvement institutions, the national grading data offer such opportunities of selecting the qualified cows and bulls that can enhance whole Wagyu quality. Wagyu grading is based on two key factors, marbling and yield, developed by the Japan Meat Grading Association. Consumers have access to the final grade of each Wagyu beef cut, offering insights into the quality of the meat they are purchasing (Wagyu Evolution, 2024).

Channels of data capture

- The system has been designed to accept reported information in virtually all communication formats: by phone, email, online portal, app, through to fax or paper form. This guarantees communication channel access for all participants (Ministry of Agriculture, Forestry and Fisheries, 2008).

Stakeholder roles and responsibilities

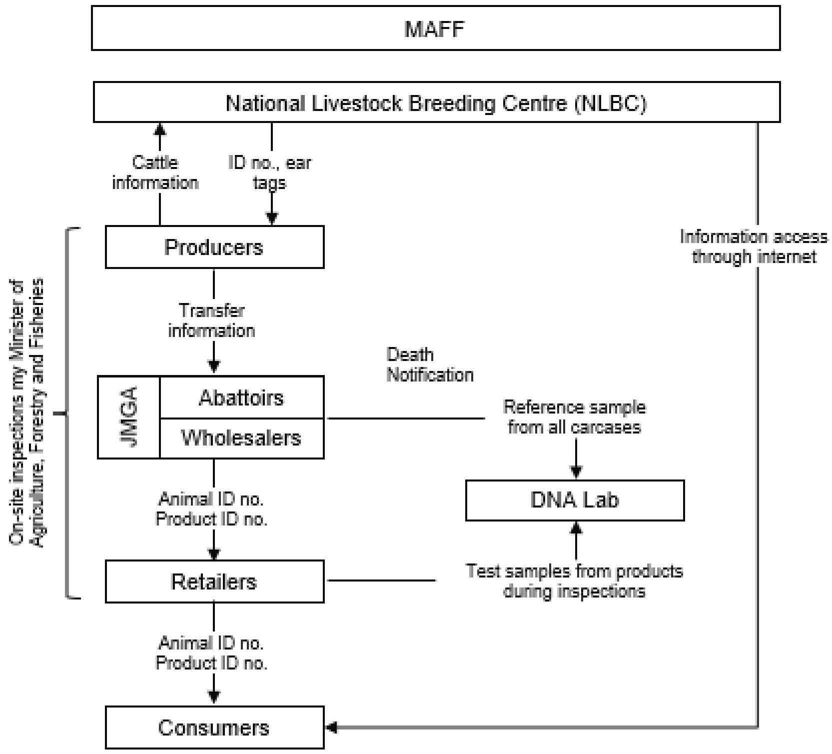


Figure 2 Stakeholders involved in Japan's livestock traceability system

Ministry of Agriculture, Forestry and Fisheries (MAFF):

- Oversees the Individual Cattle Identification Register (open access via the internet).
- Provides regulatory oversight, with officials responsible for monitoring through on-site inspections of producers, slaughterers, and sellers to ensure proper cattle identification.
- In the event of a legal breach by a stakeholder, warnings or orders are issued, and penalties are applied if these orders are not followed.

National Livestock Breeding Centre:

- Operates and manages the individual livestock identification system, provides guidance to organisations, and works with prefectures to promote the system.
- Collaborate closely with MAFF to ensure observance of the system is respected

Japan Meat Grading Association (JMGA)

- A third-party association in between meat producers and distributers that conducts grading based on grades that are nationally standardised.

Farmers/Producers:

- Required to tag animal with assigned identification number at birth.
- Whenever there are changes such as transfer of location, death, shipment for slaughter, change in ownership, etc. farmers are required to report the information to the NLBC along with the ID number.

Slaughterhouses:

- When the animal is slaughtered, the slaughterhouse is required to report information with ID to the NLBC and tag the carcase with an identification number which is linked to the IIN.

Wholesalers, retailers, meat processors, restaurants:

- All responsible for maintaining and relaying the unique identification number throughout the process chain – from slaughter to final product
- Additional ID numbers are assigned as the animal travels through the supply chain. This starts with the animal IIN, followed by carcase IIN, followed by product IIN at the wholesale/retail level. These numbers are entered by the person managing the cattle/carcase/meat at that level of the supply chain. The numbers are linked to each other and are all tracked via barcode printed on the meat packaging/carcase tags.
- Food service providers are required to ensure that products display corresponding IIN and record and preserve (maintenance of registers) sales information of these products

DNA Labs:

- Responsible for confirming alignment between DNA samples taken during inspection from both upstream (carcase sample) and downstream (from meat products)

Local councils established by prefectures:

- Facilitate promotion issues in the region, build implementation systems, provide guidance to farmers, and disseminate the system.

Multi-criteria assessment

Table 4 Scored multi-criteria assessment result – Japan

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)	H	2.5	The system generates outputs with value beyond traceability/biosecurity. It supports data collection on animal welfare, farm practices, and provides consumer confidence. It's used for herd management, proof of ownership. However, it currently lacks in value-add to carbon accounting.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	3	The system is fully applicable to livestock traceability, muzzle prints are specifically done for cattle, but it can be applied to other animals though there have been no use cases for this in Japan.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	H	2.5	In its base form, the Japanese system does not require use of advanced technologies. Visual ear tags are still largely used, and muzzle print are often collected by ink (if used at all). Communication channels include both 'modern' (e.g. website, app) and 'traditional' (e.g. fax, phone) methods to ensure that everyone has access and can participate in reporting information.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	L	1	The base system is already in use in Australia. The primary difference is in the mandatory requirement to track individual meat products with an identification number – which can be traced back to the individual animal. Japan's system requires a high level of coordination and effort from all

					participants in the supply chain. Without being legally enforced, such system is highly unlikely to be adopted in Australia.
5	**Cost**	Are costs related to a user accessing the system reasonable?	H	2.5	Whilst the tagging technology is not costly (visual ear tags, bar codes), this system is much more costly compared to Australia in terms of time and effort spent tracking and reporting information from live animal through to final meat products.
6	**Effort**	Is the contact time required of a user to engage the system reasonable?	L	0.5	In terms of tagging, the system requires manual input from users at multiple levels of the supply chain (tagging, sample collection, sending samples) comparative to that in Australia. Much of the required effort occurs post-slaughter. Identification numbers need to be assigned to individual containers of meat products, firstly through bar codes and subsequently in QR codes on the final product.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	M	1.5	Despite being a centralised system with an online platform for data access, the collection and integration of data still largely rely on manual input and coordination.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	2.5	Extensive validation includes documentary checks, pedigree confirmation, and muzzle pattern verification for Wagyu cattle, though its use for traceability is unclear. A calf registration certificate is issued after spot checks and reference DNA sample comparisons. Each beef cut is traced back to the individual animal throughout the processing chain.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	2.5	Making information regarding birth date, sex, transfer details (description, date, location, etc.), slaughter date and location, and name of parties responsible, publicly accessible to the consumers is the primarily concern of

					the Japanese livestock information system. Data access is carefully controlled centrally by the NLBC.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	M	2	The system appears robust with automated error detection and correction (e.g., for parentage), regular updates of genomic evaluations, and multiple access points (web, app), providing fail-safe recording of ID. Dual-tagging (required at birth) further minimises the chance of voiding lifelong animal traceability. However, the reliance on extensive paperwork exposes data and limits backup capabilities.

Qualitative assessment

Advantages:

1. Comprehensive coverage: The system covers all cattle in Japan from birth to slaughter or export, providing complete traceability throughout the animal's life cycle. This comprehensive approach significantly enhances food safety and disease control capabilities. Almost all cuts of meat are traceable(except for some items such as bowels, tongue, ground/minced meat) via the use of barcodes printed on meat packaging/assigned to carcase tags.
2. Transparency and consumer trust: By making most of the information publicly accessible, the system fosters transparency and builds consumer trust. Consumers can easily verify the origin and history of the meat they purchase by searching the IIN displayed on the meat packaging in the JLTS database.
3. Multi-stakeholder integration: The system effectively integrates various stakeholders including farmers, government agencies, slaughterhouses, and consumers. This broad participation enhances the system's effectiveness and adoption.
4. Support for industry development: Beyond traceability, the system supports broader industry goals such as genetic improvement, farm management, and potentially facilitates financial services (like using cattle as collateral for loans).
5. Diverse communication channels: From modern methods (e.g. email, website, app) to traditional channels (e.g. fax) ensures that all animals can be reported.

Disadvantages:

1. Limited technological sophistication: The system primarily relies on visual ear tags and manual data entry, rather than more advanced technologies like RFID or automated data collection. This could potentially lead to human errors and inefficiencies. In the case of lost or damaged tags, the same ID number can be issued and tag re-attached to the animal. There are no measures in place to flag animals that may not be fully 'life-long' traceable.
2. Narrow scope: The system appears to focus solely on cattle, potentially missing opportunities for a more comprehensive livestock traceability approach that includes other species.
3. Cost and manual effort: Although specific costs aren't detailed, the system does impose additional responsibilities and costs on farmers for tagging animals and reporting data. This could be burdensome, especially for smaller operations. The wide range of communication channels also implies a high degree of manual effort required to standardise information into the NLBC database. Lots of effort going into maintaining data record, creation of ID number, inspection and validation of results.
4. Inspection: Reporting compliance is largely validated via direct inspection processes, including manual inspection on farm and issue of certificates for new wagyu calves, and manual compliance checks and inspection by approved government inspection officers during carcass processing and meat packaging stages. Tracking, scanning and image analysis technologies could reduce this manual effort in the future.

4.2.3 Uruguay - National Livestock Information System (SNIG)

System overview

Uruguay's National Livestock Information System (SNIG) is a comprehensive traceability framework consisting of two main components: the Animal Identification and Registration System (SIRA) and the Electronic Information System of the Meat Industry (SEIIC). This integrated system tracks animals from birth to consumption, encompassing movements, health records, and processing information.

Each animal in the system is identified with two tags: a visual tag displaying a printed number and an electronic tag containing an RFID chip. The SNIG currently manages information for over 11.5 million cattle across approximately 45,000 farms throughout Uruguay (ESRI, 2013).

Implementation of the system was a gradual process, beginning with a voluntary pilot program in 2004. It became mandatory for all cattle born after 2006, and by 2011, the system had achieved full coverage of the country's entire cattle population. The primary motivation for establishing this comprehensive traceability system was to maintain and enhance the premium value of Uruguay's beef exports. Consequently, the system focuses on tracking crucial aspects such as ownership changes, location updates, health history, and detailed processing information throughout the supply chain.

Cost structure

The State finances all costs associated with tagging and record keeping in Uruguay's livestock traceability system. Producers receive identification devices (ear tags) free of charge. The system is currently funded entirely by the Uruguayan Government, with a USD1 per head slaughter fee. The system was adopted as a 'public asset' - owned by all Uruguayans, with the state deciding to finance all costs. This approach has made it possible to implement the system across the entire cattle population, regardless of the size of the farm or operation.

The government's investment in traceability innovation has yielded significant returns. For every dollar invested, benefiting activities have generated USD20 in profit, demonstrating the economic value of the system beyond its primary traceability function (Inter-American Institute for Cooperation on Agriculture, 2013).

Main benefits provided

Transparency and trust

- The system allows consumers to trace their beef back to its source, providing crucial information for health, social, and environmental considerations
- For producers, it offers detailed post-processing data on their cattle, including pricing and yield

Premium in export markets

- The system provides detailed information about the origin and history of livestock, ensuring traceability from farm to plate (via the combination of SNIG and SEIIC) and a mitigation of the fallout from potential recalls due to safety issues. This is especially important for accessing international markets, where high standards of quality and food safety are required.

Geo-referenced information

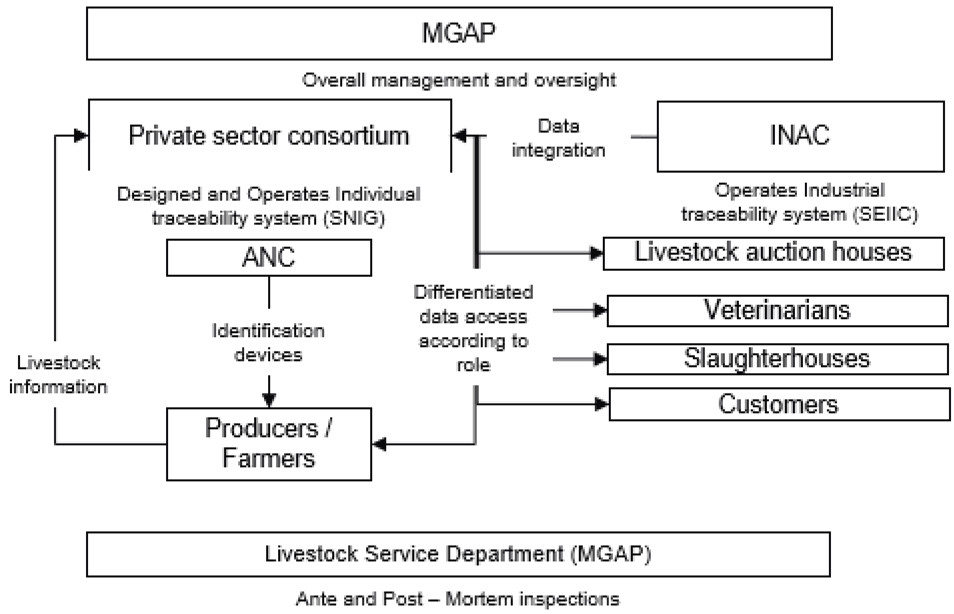
- Moreover, it supports georeferenced records. This facilitates the tracking and control of animal movements, contributing to disease prevention and enabling a rapid response to health emergencies.

Adoption cost

- Burden of cost alleviated for farmers – as tagging and record keeping costs are subsidised

Stakeholder roles and responsibilities

Figure 3 Stakeholders involved in Uruguay's livestock traceability system



Ministry of Livestock, Agriculture and Fishery (MGAP):

- Responsible for the overall management and oversight National Livestock Information System (SNIG)
- Funds and distributes identification devices to producers

National Meat Institute (INAC):

- Manages the Electronic Information System of the Meat Industry (SEIIC)
- Responsible for industrial traceability

Livestock Services Department of MGAP:

- Performs ante- and post-mortem animal inspections
- Issues sanitary certificates

Private sector consortium (including Sonda Uruguay S.A., Artech, and ICA):

- Contracted to design, implement, and operate the SNIG database

Farmers:

- Responsible for requesting ID number and tag (via internet or phone) upon animal birth.
- Responsible for providing all farm information (owner name, location, etc.) and livestock information (gender, breed, age, date of tag attachment, etc.) to SNIG

Meat processors:

- In meat processing and packing plants, products are labelled with bar codes linking them to the herd from which they originated. This information is relayed to the point of sale.
- Other end users such as auction houses, veterinarians, etc. can access data related to livestock history, health record, etc. with access authority differentiated according to their roles

Multi-criteria assessment

Table 5 Scored multi-criteria assessment result – Uruguay

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with value beyond traceability and biosecurity. It supports animal welfare, farm practices, and provides data for financial services (e.g., using cattle as collateral for loans). It also enhances Uruguay's position in global beef markets.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	3	The system is already fully applied to livestock traceability, covering the entire cattle population in Uruguay.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	H	2.5	The system primarily relies on commercially available technology such as LF RFID ear tags and georeferenced records. It also allows for offline usage for users with limited connectivity. These systems are not yet widely used in the livestock industry in Australia (e.g. LF RFID is still used in place of UHF RFID) and requires accreditation before seeing mass usage
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	H	3	In principle, the core elements of the systems can be adopted for the Australian context.
5	Cost	Are costs related to a user accessing the system reasonable?	H	3	The system is state-funded, with producers receiving identification devices free of charge. There is a$1 per head slaughter fee which is used specifically for the implementation and operation of the traceability system. This fee seems reasonable compared to the benefits provided.
6	Effort	Is the contact time required of a user to engage the system reasonable?	H	2.5	While much of the system is automated, some manual data entry is still required, especially for on-farm events. However,

					efforts are being made to increase automation and reduce paper-based processes.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The system integrates data from various sources (on-farm, transportation, slaughterhouses) and can share data with different stakeholders. It also incorporates GIS functionality. The system integrates and provides information to other information systems, such as SEIIC, the animal health system, INAC, among others. The system also interfaces with Uraguay's National Institute for Meteorology (INUMET) and Agroclimate and Information Systems Unit (INIA/GRAS), to enable cross sectoral insights and identify seasonal trends in production and on farm activity, over time.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	M	2	The system includes multiple validation methods, such as automated cross-checks, manual audits, and DNA sampling for verification. Despite institutional oversight and control, manual data entry still makes the system prone to errors.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	2.5	Each participating actor has different privileges that give authorised access to distinct data and functionality within the central database. For example, breeders may access maps of their farmlands and data on activities or animal species through their respective registration numbers. Veterinarian services may access maps showing rings of neighbouring farms, data used in case of animal diseases.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	3	The system includes features like local servers in processing plants, contingency plans for data recovery, and the ability to work offline when necessary, indicating good resilience.

Qualitative assessment

Advantages:

1. Comprehensive coverage: the system covers the entire cattle population in Uruguay, providing complete traceability from birth to plate. This comprehensive approach enhances food safety, disease control, and market access.
2. State-funded model: by treating the system as a public asset and covering the costs, Uruguay has ensured widespread adoption and eliminated financial barriers for producers. This approach has enabled even small-scale farmers to participate fully in the system.
3. Integration of multiple technologies: the system combines various technologies (RFID, barcodes, GIS, web and mobile applications) to create a robust and versatile traceability solution. This integration allows for efficient data collection, management, and analysis at different stages of the supply chain.
4. Market access and product differentiation: the system has enhanced Uruguay's reputation in the global beef market, opening doors to premium export markets and potentially allowing for higher prices. It provides a strong foundation for certifying product quality and origin.
5. Multi-stakeholder benefits: the system provides benefits to various stakeholders, including farmers, industry players, regulators, and consumers. It offers management tools for farmers, enhances industrial efficiency, supports regulatory oversight, and provides transparency for consumers.
6. Connectivity: the system accommodates for offline data capture, storing new information locally when there is no connectivity then syncing with the database once connection is established, which enhances usability in low-connectivity regions

Disadvantages:

1. Reliance on state funding: while the state-funded model has advantages, it also means the system is dependent on continued government support and budget allocations. This could potentially make it vulnerable to changes in political priorities or economic conditions
2. Complexity and training requirements: the comprehensive nature of the system, while beneficial, also implies a level of complexity that may require ongoing training and support for users, especially as new features or technologies are introduced.
3. Potential for data overload: with such a comprehensive system collecting data on millions of animals, there's a risk of generating more data than can be effectively utilised. Ensuring that the collected data translates into actionable insights could be challenging.

4.2.4 South Korea

System overview

The Animal Products Traceability System in South Korea is a comprehensive framework designed to track and manage information about livestock and animal products throughout the entire supply chain, from birth or production through to consumer purchase. This system, initially focused on cattle, is sometimes referred to as the Beef Traceability System or the Hanwoo Traceability System, reflecting its original application to native Korean Hanwoo cattle (Ki Yong Chung, Seung Hwan Lee, Soo Hyun Cho, Eung Gi Kwon, and Jun Heon Lee, 2018)

For cattle, the system employs a 12-digit individual animal identification number (separate to the Japanese traceability system) and incorporates DNA testing to verify the identity and origin of beef products. Implemented in 2008, it was designed to fully trace cattle from birth to slaughter, with DNA samples taken at various stages of the supply chain to validate product authenticity.

Since its inception, the system has expanded to include other livestock species:

- For pigs and pork, the traceability system was designed primarily for disease control. Unlike beef, the individual identification number for pork is only generated at the slaughtering stage based on the farm ID number.
- The system also covers chickens and other poultry.

The implementation of this traceability system has had significant economic impacts. Notably, Korean cattle prices recovered dramatically from July 2009, following the system's introduction (MLA, 2017).

Main benefits provided

Birth-to-plate traceability

- By law, individual identification numbers are assigned to the animal within one month from birth. Its carcase is assigned a number and the individual cuts of dressed meat along the supply chain are also assigned numbers which are all linked to the live animal individual identification number.
- Consumers and other industry stakeholders can verify identity of animal, along with DOB, gender, breed and movement history, by accessing the centralised 'Animal Products Traceability' or 'MTRACE' database (www.mtrace.go.kr) and entering the animals 12-digit identifier or lot number. The database is maintained by Government and able to be accessed via desktop or smartphone. Consumers can also contact dedicated MTRACE regional call centres.

Fraud prevention

- DNA samples are extracted from all carcases and selected meat products. These are stored in the DNA laboratory of KAPE and analysed to confirm authenticity between pre and post meat work products, by collecting random samples from retail shops,though this cannot be done in real time.

Transparency and trust

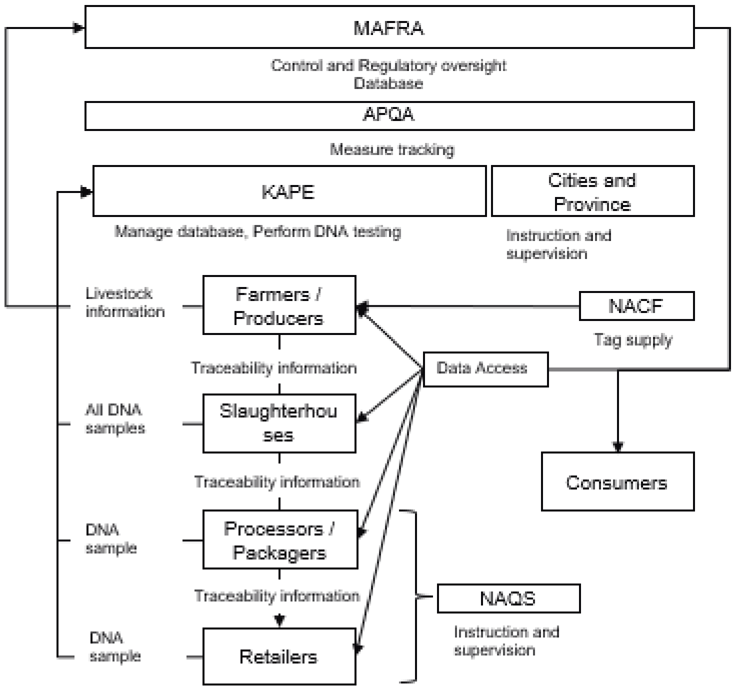
- The system provides processors, retailers and consumers with the ability to verify product origin and quality – ensuring confidence in food quality and safety

Disease control

- In case of animal diseases such as foot-and-mouth disease, to manage risks such as preventing the spread of disease by promptly tracing and controlling, allowing to take a quick action by collecting and disposing of meat

Stakeholder roles and responsibilities

Figure 4 Stakeholders involved in South Korea's livestock traceability system



Government agencies:

- Ministry of Agriculture, Food and Rural Affairs (MAFRA) : Overall responsibility for the system in terms of planning, supervision, and policy development. It also has the authority to issue fines in cases of misconduct or legal violations.
- Animal and Plant Quarantine Agency (APQA) : Responsible for addressing issues related to traceability numbers for imported beef, as well as collecting and inspecting samples for disease/ epidemiological investigation
- Korea Institute for Animal Products Quality Evaluation (KAPE): practical promotion of the system, delegated by the MAFRA . It manages the database, conducts carcass grading, correct errors, and performs DNA testing
- Cities and Provinces: Appointed by the MAFRA with responsibilities in instructing and supervising of breeding, slaughtering, packaging, and selling stage
- National Agricultural Products Quality Management Service (NAQS): Appointed by the MAFRA with responsibilities in instructing and supervising of packaging, and selling stage

Farmers/Producers:

- Responsible for tagging animals, reporting births, movements, and other events
- When a calf is born, farmers are responsible to report it in writing within 5 days. An ear tag is required to be attached within 30 days for dairy cattle (7 for beef cattle)
- When the animal is transferred, acquired, or dies, it must be reported within 5 days to the system
- When shipping for slaughter, information such as the shipping farm's personal information and history number must be notified to the slaughterhouse on the slaughter inspection application form.

Slaughterhouses:

- Verify animal identification, conduct health inspections, attach labels to carcases
- Slaughterhouses are responsible for checking the IIN number indicated on the slaughter inspection application form against that on the ear tag, and whether it is registered in the history management system
- Slaughter inspector inputs pass/fail results into system
- Carcase numbers are again checked against history number. Label with history number is printed and attached to animal carcase.

DNA labs / inspectors:

- DNA samples of carcase are taken and mailed to Livestock Product Quality Evaluation Institute. After checking the history number, the livestock product quality evaluator enters the grading details and transmits the data. The collected DNA samples are stored at the Livestock Product Quality Evaluation Institute.
- Confirmation of DNA identity between samples collected at the slaughterhouse and samples collected at the packaging/sales facility

Processors and Packagers:

- Ensure traceability through processing and packaging stages by attaching a label with a history number to each part of the meat packaged on the packaging and report the packaging processing performance electronically within 5 days.
- This process follows every individual item through to shipment

Retailers:

- After checking the history number, small division work is done per unit.
- Small division packaged meat is marked with the same number as the beef history number on the packaging, etc.

Consumers:

Can access traceability information via the MTRACE database, which is accessible via desktop, smartphone, or by contacting the MTRACE call centre. Traceability is via an animal's unique, 12-digit identification number, or lot number, which is entered to the MTRACE portal. The record retrieved includes information on the animal (DOB, type, gender), Ownership (owner's name, location); Slaughter (abattoir location, slaughter date, inspection results, meat quality processing/packing), and Health (FMD vaccination, other treatments).

Multi-criteria assessment

Table 6 Scored multi-criteria assessment result – South Korea

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with value beyond traceability/biosecurity. It provides data for breeding value estimation, supports food safety, enhances consumer confidence, and aids in disease control. It also supports premium pricing for high-quality products.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	3	The system is already applied to livestock traceability, covering multiple species including cattle, pigs, chickens, and eggs. It's fully operational and integrated into the livestock industry.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	H	2.5	The technology used in the South Korean system (RFID tags, DNA testing, computerised databases) is mature and has been in operation for ~15 years. In contrast, these systems are not yet widely used in the Australian livestock industry, where LF RFID is still in use instead of UHF RFID, and mass adoption requires further accreditation.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	2	The system has been widely adopted across the South Korean livestock industry. It's mandatory and integrated into all stages of the supply chain. It also extends to other livestock such as pigs, chicken and duck. This level of complete coverage, in principle, can be adopted in Australia – however, it needs to be driven by legal mandates to be carried out at a national level.
5	Cost	Are costs related to a user accessing the system reasonable?	M	2	While specific cost information isn't provided, the system involves ongoing expenses for tagging, DNA testing, and database management. These costs are likely shared between the government and industry participants but may be higher than previous systems.

6	**Effort**	Is the contact time required of a user to engage the system reasonable?	L	1	Similarly to Japan, the system requires ongoing input from different users across the supply chain (e.g. sample collection). While some processes are automated, there's still a need for manual data entry and physical checks at various stages. A significant amount of time and effort is required from farm to retail to track animal IIN and relaying this information through to individual meat products.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	2.5	The system integrates data from multiple sources (farms, slaughterhouses, processors, retailers) into a centralised database. It allows data sharing across the supply chain and with consumers.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	2.5	The system incorporates multiple validation methods, including DNA testing at the slaughter phase and physical checks throughout the supply chain, with animal identification numbers manually verified at every touchpoint.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	2.5	Data are stored in a centralised database under the supervision and protection of the central authority. There are ongoing initiatives to transition the system to blockchain for enhanced security and integrity.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	M	2	Despite being operational for over a decade and expanding to include multiple species, the system still relies heavily on paperwork. This extensive use of physical documents limits the backup capabilities of the system in case of document loss, even with the presence of an online platform.

Qualitative assessment

Advantages:

1. Comprehensive coverage: the system covers multiple species (cattle, pigs, chickens, eggs) and tracks animals from birth through to retail sale. This comprehensive approach enhances food safety and traceability across the entire livestock industry. Its advantages in terms of food safety, genetic improvement, and consumer transparency are significant.
2. Integration of advanced technologies: the system combines RFID tagging with DNA testing, providing a robust method for animal identification and product verification. This dual approach significantly reduces the risk of fraud or errors in traceability.
3. Support for genetic improvement: by linking individual animal data with carcase and performance information, the system supports genetic evaluation and breeding programs. This can lead to long-term improvements in livestock quality and productivity.
4. Consumer transparency: the system allows consumers to access detailed information about the products they purchase, enhancing trust and potentially supporting premium pricing for high-quality products. A study by Kangwon National University has directly attributed the introduction of Korea's beef traceability system with the country's cattle value (Kangwon National University, 2011)
5. Disease control capability: the system's ability to track animal movements (though within a 5 day reporting window) and health records provides a powerful tool for managing disease outbreaks, potentially limiting their spread and economic impact.

Disadvantages:

1. Complexity: the system's comprehensive nature may make it complex to manage and maintain. This complexity could lead to increased costs and potential points of failure.
2. Cost burden: while specific costs aren't detailed, implementing and maintaining such a comprehensive system likely involves significant ongoing expenses. These costs may be particularly burdensome for smaller producers.
3. Potential for over-regulation: such a comprehensive, mandatory system might be seen as overly burdensome regulation by some industry participants. It may reduce flexibility in production practices and increase administrative workload for farmers and processors.

4.2.5 Digital ID

System overview

The overall system is generally referred to as "Digital Identity" or "Digital ID". Some notable commercial use cases in Australia include:

- myGovID - A digital identity app created by the Australian government that allows citizens to prove who they are online. It can be used to access government online services and verify identity for other purposes (Australian Government, 2024).
- Australia Post Digital iD - A digital identity service created by Australia Post that allows users to verify their identity once and then reuse it across multiple services and in-person scenarios. (Digital iD, 2024)

- Relationship Authorisation Manager (RAM) - A system that works with Digital Identity to allow businesses and individuals to manage who can act on their behalf for government online services (Australian Government, 2024).
- Australian Agricultural Traceability Protocol (AATP): a data governance protocol designed for Australian agricultural producers. It connects the digital identity of agricultural products with related data about their ESG credentials, such as sustainable land use, emissions and ethics. The AATP is based on a decentralised data architecture, which keeps data at its source and extracts information when needed for specific purposes – with consent of data owners and providers. By linking data sources, the AATP connects the digital identity of the object (e.g. livestock or red meat products) to the information relating to the object.
- It has been rolled out across various government services and is being adopted by private sector organisations as well.

Cost structure

For individuals, setting up and using Digital ID is free. For businesses, there may be integration costs. In relation to cost-recovery, the DTA notes that "Australians will not need to pay to use the System". The charging framework will only apply to businesses and governments who will participate in the System'. However, the charging framework has not been released and is still under negotiation with stakeholders (Parliament of Australia, 2022)

The Government will provide $145.5 million over four years from 2023–24 (and $17.0 million per year ongoing) to support the next stages of the Digital ID program and related identity security initiatives (Australian Government, 2023)

Main benefits provided

Paperless identification

- Single digital identity for a wide range of use cases – removing the need to carry paper-based identification documents

Streamlined service access

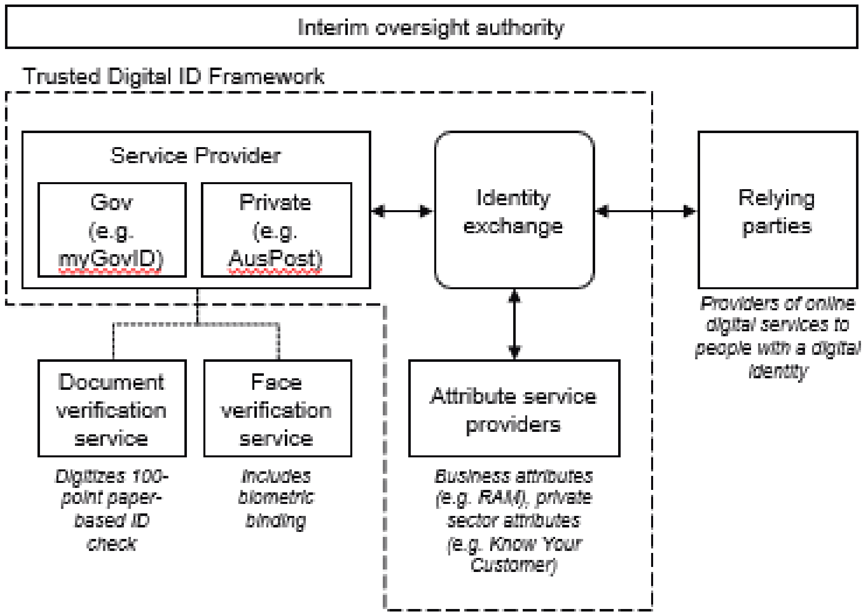
- Identity can be used to automate lookup/integrate across multiple databases (e.g. Centrelink, ATO, etc.) (Australian Government, 2024)
- Negates need for multiple logins to access different services
- In the example of AATP, stakeholders along the supply chain (e.g. regulators) would rely on digital credentials to 'discover' information relating to the product (e.g. livestock or meat product), rather than requesting and reviewing specific paper or digital forms.

Security

- Digital ID reduces the number of places ID information is stored and verified – reducing the risk that information is stolen or exposed in third-party data breaches
- Providers of Digital ID systems must be accredited and follow strict privacy safeguards

Stakeholder roles and responsibilities

Figure 5 Stakeholders involved in the Trusted Digital ID Framework



Australian Government: the Australian Government Oversight Authority currently oversees the Trusted Digital Identity Framework (TDIF). They currently manage:

- Accreditation, approval, suspensions and termination of organisations in the system
- Monitoring and compliance of these organisations against the standards
- Inquiries and investigations of the system such as system incidents, fraud and security
- Complaints and issues handling for organisations participating in the system

Service providers:

- Currently both Government and Private service providers are available (e.g. AusPost). They are responsible for developing, maintaining and operating the digital ID services.
- In the future, it is envisioned that other parties such as financial institutions can also offer digital ID services

Digital Transformation Agency (DTA):

- Collaborated with Australia Post on Digital Identity integration

Private sector organisations:

- Adopt and integrate Digital Identity solutions into their services

End users:

- Include individual citizens, businesses (RAM), government agencies and private organisations

Relying parties:

- The System currently provides access to over 80 services offered by the Australian Government, for example, to apply for a Tax File Number, an online Customer Reference Number, a Unique Student Identifier, or a company director identification number.
- Various departments (e.g., ATO, Centrelink) are currently relying on the system to provide access to their service
- This can be extended to include financial institutions, utility providers, etc.

Multi-criteria assessment

Table 7 Scored multi-criteria assessment result – Digital ID

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	L	1.5	In its current state, digital ID systems are mainly used in identity verification, providing ease of access to online government services, parcel collection, and creating statutory declarations. While it may be able to streamline paperwork processes in the livestock journey (e.g. signing, NVD handover) or provide verified connection to other Agtech technologies, it does not have clearly defined possible use cases in farm practices, carbon accounting, animal welfare, etc.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	M	2	Digital ID has already been applied across government services and private sector applications, showing it can be easily adapted to new use cases. In Australia, AgTrace is a notable example in livestock context.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	H	3	The technology is readily accessible to users in the Australian context. It primarily relies on smartphones and apps, which are widely available to most Australians.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	H	2.5	The system appears to be easily adoptable for most users, with a straightforward setup process. However, some users might face challenges, particularly those less comfortable with technology or without smartphones.
5	Cost	Are costs related to a user accessing the system reasonable?	H	2.5	While the system is free for individual users, there may be costs for businesses integrating the system.
6	Effort	Is the contact time required of a user to engage the system reasonable?	H	3	Once set up, the system seems to require minimal effort from users where only an ID and password is required. It automates many processes that previously required manual verification, significantly reducing user effort.

7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The system shows high interoperability, working across various government services and private sector applications. It can receive and output data to multiple platforms.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	3	The system uses robust validation methods, including document verification against official records and biometric checks for higher security levels. It's not solely reliant on self-reported information.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	M	2	The system employs strong security measures, including encryption, decentralised storage, and user consent for data sharing. It also uses multi-factor authentication for added security. However, storage of personal (including biometric) information can also be seen as a point of vulnerability.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	M	2	While the system appears robust, there's limited information about backup systems or error recovery processes. The decentralised storage approach provides some resilience, but more information would be needed for a higher score.

Qualitative assessment

Advantages:

1. Convenience and efficiency: the system streamlines identity verification across multiple services, both government and private sector. Users can prove their identity once and reuse it, saving time and reducing bureaucracy.
2. Enhanced security: by using advanced encryption, decentralised storage, and multi-factor authentication, the system offers robust protection against identity theft and fraud, potentially more secure than traditional paper-based methods.
3. User control and privacy: the system emphasises user consent and control over personal data. Users decide when and with whom to share their information, enhancing privacy protection.
4. Flexibility: the system has been used commercially in several use cases, from accessing government services to age verification at venues. This flexibility suggests potential for further expansion and integration with other services. However, further investigation is required to understand its limitations if applied in the livestock context.
5. Digital transformation driver: by providing a secure and standardised digital identity solution, the system accelerates Australia's broader digital transformation efforts, potentially improving efficiency across various sectors.

Disadvantages:

1. Digital divide: the system's reliance on smartphones and digital literacy may exclude or disadvantage certain populations, particularly older individuals, those in rural areas with limited connectivity, or people who can't afford smartphones.
2. Single point of failure: despite security measures, if a user's digital identity is compromised, it could potentially affect access to multiple services. This concentrates risk compared to separate identity systems for different services.
3. Adoption challenges: convincing all relevant stakeholders (government agencies, businesses, and citizens) to adopt and trust the system could be challenging, potentially leading to a fragmented identity landscape if not universally adopted.
4. Technological dependence: the system's reliance on technology means that technical issues, such as app malfunctions, server downtimes, or connectivity problems, could temporarily prevent access to essential services.

4.2.6 DNA-based technologies

System overview

DNA traceability or genomic traceability is a technology-based approach that uses DNA analysis and genomic tools to track and verify the origin, authenticity, and characteristics of animals and animal products throughout the supply chain. This method employs various techniques depending on the test purpose and information sought.

Notable examples of DNA traceability techniques include: DNA tagging/molecular markers, Genotyping, Isotope analysis, PCR (Polymerase Chain Reaction) testing.

In recent years, novel technologies such as DNA pooling or flock profiling have emerged, allowing for the assessment of quality in animal herds, such as wool quality in sheep flocks (P.M. Gurman, K. Gore and D.J. Brown, 2023)

The applications of DNA traceability are diverse and include: verification of origin, breed of animals and animal products, detecting product adulteration or mislabelling, birth to consumer traceability, identifying genetic traits related to disease resistance, productivity, or quality, supporting food safety and recall systems, verifying compliance with regulations (e.g. bans on products from certain regions. (DNA Traceback, Safetraces)

Cost structure

Genotyping costs range from AU$15 for parentage testing to AU$40-70 for 100k SNP chips (Australian Sheep Genetics, 2023). These figures typically include sampling operational costs.

The funding model for DNA traceability systems varies depending on the specific implementation. Common approaches include:

- Government funding for national-level systems (e.g., Uruguay's system)
- Industry-funded initiatives (e.g., retailer-led programs)
- Cost-sharing between supply chain partners
- Integration of costs into product pricing

In many cases, the added value of traceability, such as access to premium markets and risk mitigation, is used to justify the costs to participants. The specific funding approach often depends on the scale of implementation and the regulatory environment in a given country or industry.

While costs associated with tagging, sampling and testing are decreasing due to ongoing research and investment, current technologies make it challenging to reduce test costs below $10. Despite this, the benefits of DNA traceability often outweigh the costs, particularly for high-value products or in markets where traceability is highly valued. Cost of DNA sample storage also remains a major barrier for adoption.

Main benefits provided

Valuation

- Performance valuation of individual animal to inform selection for feedlot, breeding, etc.
- Techniques such as DNA pooling or herd profiling are often employed to allow farmers to monitor performance and traits at herd level
- Prediction of potential animal meat quality also allows grading

Parentage and product traceability

- Parentage confirmation is commonly required in systems such as Ireland
- Product authenticity validation is done in some country markets (e.g. Korea, Japan) to prevent against fraud
- In most cases, traceability is a secondary benefit. In these cases, DNA verification of animal improves Regulator’s ability to enforce trade regulations and food safety standards.

Product premium

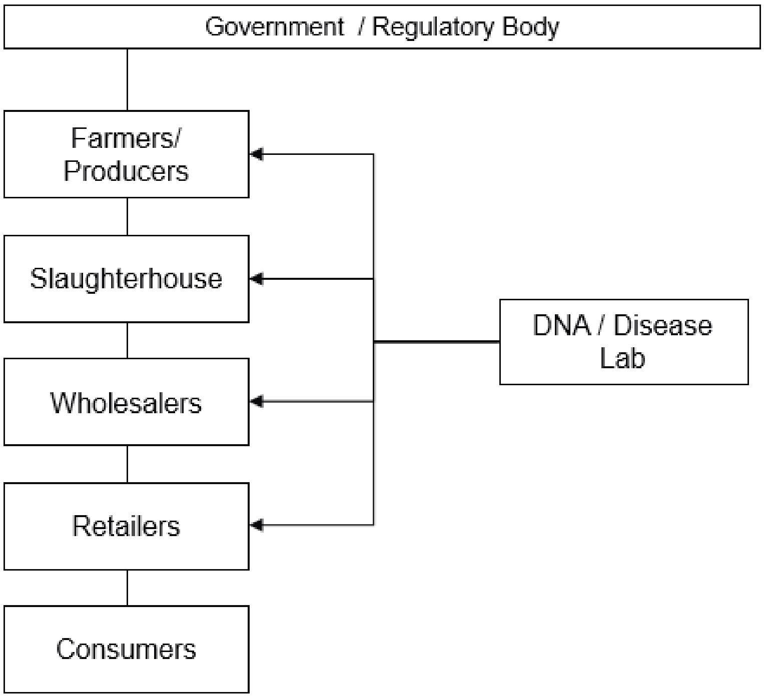
- In premium cases such as Wagyu, DNA-based traceability is desirable as it enhances consumer trust and ensures product premium when exported

Disease control

- Genomic analysis may allow early identification of disease susceptibility or indicators, to support the management of risk

Stakeholder roles and responsibilities

Figure 6 Stakeholders involved in DNA-based technology systems



Government / Regulatory bodies:

- Set regulations and standards for traceability
- Enforce compliance (e.g., customs agencies)
- May operate national-level traceability databases

Technology providers (e.g., Applied DNA Sciences, IdentiGEN):

- Develop and supply DNA testing technology
- Provide testing services and data management platforms

Producers/Farmers:

- Implement tagging and data collection at the farm level
- Provide samples for DNA testing

Processors and Manufacturers:

- Maintain traceability through processing stages
- May conduct or facilitate testing

Retailers:

- Ensure traceability of products they sell
- May require suppliers to participate in traceability programs

Third-party certifiers/auditors:

- Verify compliance with traceability standards

Multi-criteria assessment

Table 8 Scored multi-criteria assessment result – DNA-based technologies

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with value beyond traceability and biosecurity. It increases livestock genetic-based value proposition and supports animal welfare, breeding programs, and can contribute to carbon accounting and sustainable farming practices.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	L	1	It is unlikely that traceability will ever become the primary driver for adopting DNA test (mainly done for valuation, performance, supply chain optimisation, etc.). Traceability is only a secondary benefit.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	M	2	DNA-based technologies are already employed in Australia. However, lab access is a limiting factor if DNA testing is done purely for traceability of the national herd.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	1.5	Implementing a DNA traceability system requires specialised expertise (i.e. lab access) which can create barriers for smaller producers and limit adoption. In Australia, DNA technologies are mainly used for valuation, not traceability, due to high costs, test volumes and challenges associated with sample storage.
5	Cost	Are costs related to a user accessing the system reasonable?	L	0.5	The implementation and ongoing operation of DNA traceability systems can be costly and is only performed for specific valuation reasons (e.g. seed stock selection). It can potentially act as a mechanism to trace individual animal back to the herd (if individual validation is required). Some techniques, such as DNA pooling, are potential methods to cost-effectively create a genetic profile for the entire herd. Aside from valuation services, it is highly unlikely that DNA technologies will be used solely for traceability purposes in Australia.

6	**Effort**	Is the contact time required of a user to engage the system reasonable?	M	2	Some systems (e.g. Ireland) have combined sample extraction into the tagging process, though these tags are not tamper-proof so may not provide product verification. Others (e.g. Korea) require governmental inspectors to manually collect DNA samples from slaughterhouses and meat distributors for testing. DNA testing is an inherently time-consuming process (i.e. several days to produce result) and may require multiple samples to be submitted.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	M	2	DNA test results are often integrated / input directly into the livestock management system by the regulatory body. In markets such as Australia, the database is largely decentralised – where farmers operate independent on-farm software. Data is sent and needs to be standardised by regulating body (e.g. MLA, Agricultural Business Research Institute).
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	2.5	DNA testing provides a high level of validation, superior to self-reporting or third-party assessment alone. It offers scientific verification of claims.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	2.5	While the system handles sensitive data, it typically employs strong security measures under the supervision of the livestock managing authority, including encryption and controlled access, to protect user privacy and confidentiality.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	2.5	These systems often have robust backup and recovery mechanisms, with data stored in multiple locations and automated error detection/correction systems in place.

Qualitative assessment

Advantages:

1. Enhanced traceability and transparency: The system provides unparalleled accuracy to trace animals and animal products from farm to consumer. This level of transparency builds trust among consumers and trading partners, potentially opening new market opportunities.
2. Improved food safety and fraud prevention: DNA-based traceability allows for accurate identification of the source of foodborne illnesses or contamination. It also helps prevent food fraud by verifying the authenticity of premium products or breeds.
3. Support for breeding programs and genetic improvement: The genetic data collected can be used to inform breeding decisions, helping to improve desirable traits in livestock populations over time. This can lead to increased productivity and disease resistance.
4. Compliance with stringent regulations: As regulations around food safety and ethical sourcing become more stringent globally, this system provides a robust way to demonstrate compliance, potentially easing trade and regulatory burdens.
5. Value addition and product differentiation: DNA traceability allows producers to verifiably differentiate their products based on breed, origin, or production methods. This can support premium pricing and create new value propositions in the market.

Disadvantages:

1. High implementation and operational costs: The system requires significant upfront investment in technology and infrastructure, as well as ongoing costs for testing, data management and storage of samples. This could be particularly burdensome for smaller producers.
2. Complexity and technical expertise required: Implementing and maintaining a DNA traceability system requires specialised knowledge and skills. This could be challenging in areas with limited access to technical expertise or training.
3. Potential for creating market barriers: While the system can open new markets, it may also create barriers for producers who cannot afford or implement the technology, potentially leading to market consolidation or exclusion of smaller players.

4.2.7 Blockchain

System overview

Blockchain is a decentralised and distributed digital ledger technology that ensures registered transactions cannot be altered retroactively. It has been utilised in several livestock traceability systems - most notably in Zimbabwe. The technology has also seen commercial applications in traceability across various industries.

Notable use cases include:

- IBM Food Trust: a supply chain traceability system for the food industry, tracking products from farm to consumer (IBM, 2024)
- iFoodDS Trace Exchange: a joint solution with IBM Food Trust aimed at helping companies comply with the FDA's Food Safety Modernisation Act (FSMA) (iFoodDS, 2024)

- Mastercard Provenance: a traceability and multi-rail B2B payments solution (combined) providing end-to-end visibility (Mastercard, 2024)
- Tracing avocados from Australia to Southeast Asia
- Tracking commodities like coffee, sorghum, and grain in Latin America and North America

Blockchain technology's application extends beyond agriculture and food, proving applicable to various industries including pharmaceuticals, luxury goods, and minerals. Its ability to create an immutable record of transactions and movements makes it a powerful tool for enhancing transparency and trust in supply chains.

The adoption of blockchain in traceability systems demonstrates the technology's potential to revolutionise supply chain management, offering improved security, transparency, and efficiency. As the technology matures and becomes more widely adopted, it is likely to play an increasingly significant role in global trade and product verification systems.

Cost structure

Costs for blockchain-based traceability systems vary according to the selected provider. Pricing models typically include:

- Monthly fees: For example, IBM Food Trust starts from $100 per month (IBM, 2024)
- Per-transaction fees: Hedera charges between $0.0001 to $0.01 per transaction (Hedera, 2024)
- Custom pricing models: Mastercard Provenance tailors its pricing based on user data needs (Mastercard, 2024)

Blockchain platforms are often built, deployed, and maintained by large technology companies such as IBM, Mastercard, and nChain. Consequently, ongoing costs are generally recovered through subscription or usage fees.

In some cases, particularly for national-level systems, governments provide subsidies to support implementation and operation. Examples of this include blockchain traceability systems in Zimbabwe and Uruguay, where government funding helps offset costs for industry participants.

Main benefits provided

Security and data integrity:

- Cryptographic techniques ensure the security and integrity of the data – no single entity can alter the transaction history

Transparency:

- Transactions are visible to all participants in the network, enhancing transparency
- Data can be accessed in real-time

Improved supply chain efficiency:

- Removes the need for intermediaries and helps to remove bottlenecks in the supply chain
- Enabling real-time traceability of supply chain activities, including goods distribution, administrative processes, and financial transactions

- With 'smart contract solutions', a blockchain network itself can trigger transactions automatically. It helps recognised parties in the supply chain to create efficiency with security across processes

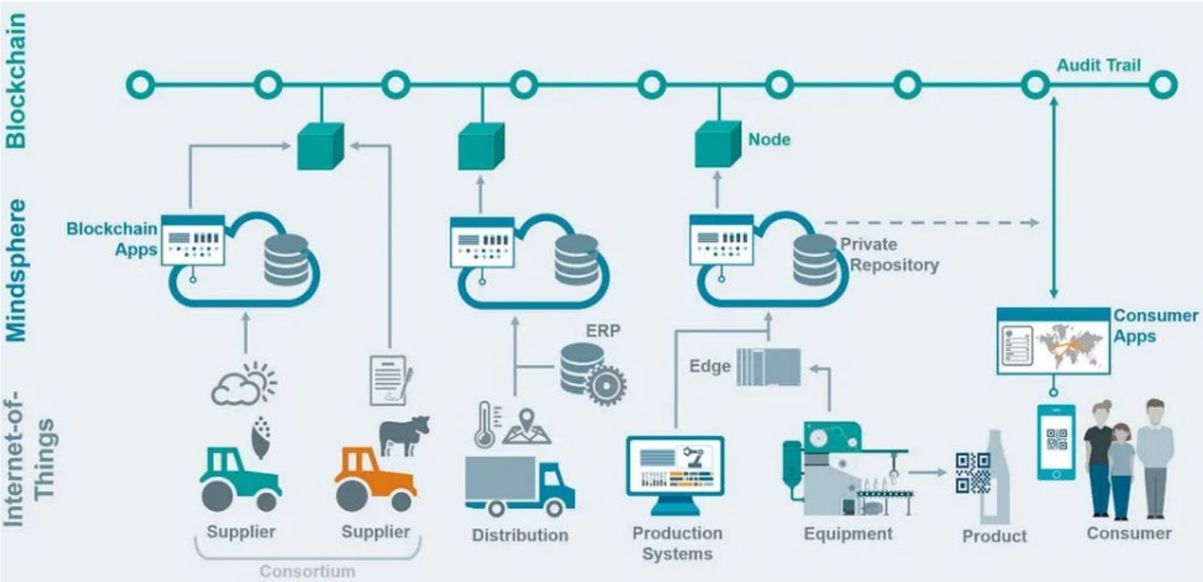
Asset provenance:

- Blockchain can record the history of an asset, detailing every transaction from creation to current ownership. This is crucial for supply chain management, where tracking the origin and journey of goods is essential.

Figure 7 Stakeholders involved in commercial blockchain ecosystems

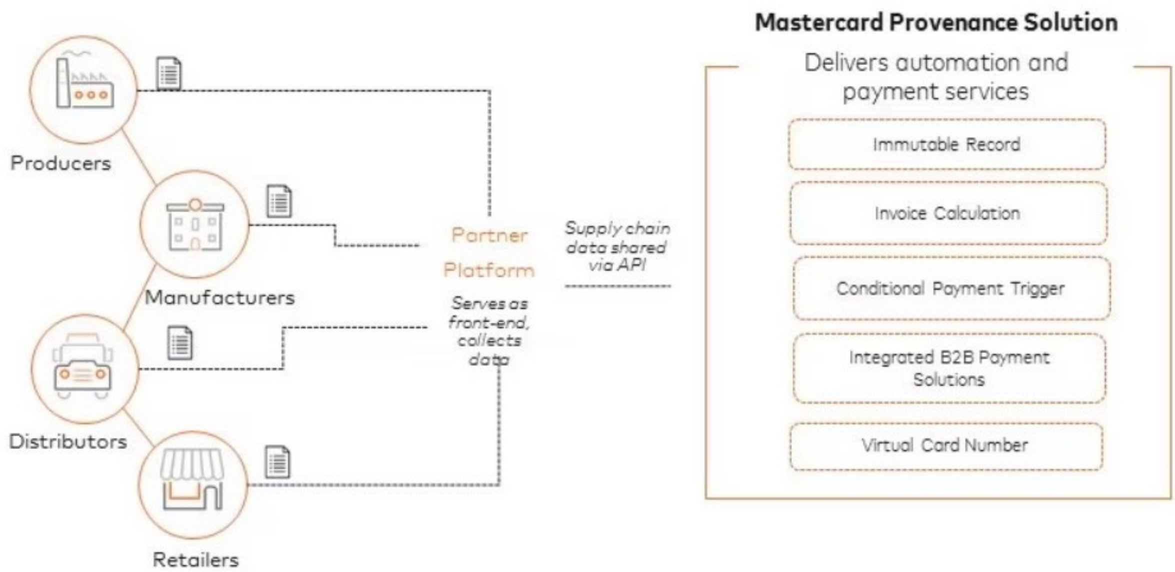
Stakeholder roles and responsibilities

Illustrative example – blockchain's role in agriculture value chain



Source: Mastercard

Illustrative example - Mastercard Provenance blockchain solution



Source: Siemens

Technology providers (IBM, Mastercard, Hedera):

- Develop and maintain the blockchain platforms
- Provide API access to integrate with databases existing along the supply chain
- Provide technical support and updates
- Development of modular, value-added components to blockchain platform, such as automatic invoice calculator, conditional payment trigger, integrated B2B payment solutions, etc.

Governments (e.g., Uruguay, Zimbabwe):

- Responsible for implementation and enforcement of traceability regulations

Food/Livestock Producers:

- Input initial data about products and animals
- Maintain records throughout the production cycle

Processors/Manufacturers:

- Add processing and transformation data along the supply chain – this could be done manually or automatically via production systems

Distributors/Retailers:

- Provide transportation and sales data
- Use systems for inventory management and recalls

Regulators (e.g., FDA):

- Use systems to verify compliance with regulations

Consumers:

- Access product information through apps or QR codes

Multi-criteria assessment

Table 9 Scored multi-criteria assessment result – Blockchain

No.	Criteria	Definition	Score		Scoring rationale
1	**Utility**	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	These systems offer value beyond traceability and biosecurity. They provide benefits in food safety, supply chain efficiency, waste reduction, consumer trust, and support for sustainability claims. Some, like Mastercard's system, has the potential to facilitate B2B payments and financing.
2	**Extension**	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	3	While originally focused on food traceability, these systems have been successfully applied to livestock traceability (e.g., Uruguay's SNIG, E-Livestock Global in Zimbabwe) and other sectors (e.g., Mastercard's system for minerals and luxury goods).
3	**Technology**	Is the technology required to engage the system readily accessible (for typical users)?	M	2	The core blockchain technology is sophisticated, but user interfaces can be designed to be accessible. Adoption of a blockchain system requires support from commercial technology providers (e.g. nChain, Mastercard, etc.) to provide a fit-for-purpose solution.
4	**Adoptability**	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	H	2.5	Implementing blockchain technology for livestock traceability generally involves initial governmental orchestration and a partnership with a technological provider for the blockchain platform. Once these steps are established, the system becomes relatively easy for users to adopt for users.
5	**Cost**	Are costs related to a user accessing the system reasonable?	L	1	Upfront infrastructure, setup costs for implementation and funding structure (i.e. 'who pays') are likely significant. However, potential benefits in efficiency, market access, and differentiation could offset these expenses for many users. Some systems (like E-Livestock Global) aim to provide financial benefits by supporting the entire supply chain with verifiable data that help justify the costs. For farmers, in

					particular, this system provides a proof of ownership, support sales and exports, and allows them to use their cattle as collaterals for loans.
6	**Effort**	Is the contact time required of a user to engage the system reasonable?	M	2	While the system theoretically can automate data logging and improve supply chain efficiency, this has yet to be demonstrated in practice. In existing limited use cases, there is still a need for manual data entry, despite ongoing exploration of automation.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	Most blockchain systems are designed to integrate with existing enterprise systems through APIs. They often support industry and global standards (like GS1), enhancing data sharing across different platforms.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	3	Blockchain technology provides a high level of data validation through cryptographic techniques that ensure the security and integrity of the data, preventing any single entity from altering the transaction history. Additionally, third-party auditors can validate data on these platforms.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	3	Blockchain technology provides high data security. Access is permissioned, and data is encrypted. The involvement of major tech companies (IBM, Mastercard) and national governments (Zimbabwe) suggests robust security measures.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	3	The distributed nature of blockchain makes these systems highly resilient. National-level implementations (like in Zimbabwe) and the involvement of major global companies suggest robust backup and recovery systems.

Qualitative assessment

Advantages:

1. Enhanced traceability and transparency: blockchain systems provide end-to-end visibility of the supply chain, allowing stakeholders to trace products from origin to consumer. This significantly improves food safety, reduces the time needed for recalls, and increases consumer trust.
2. Improved data integrity and security: the use of blockchain technology ensures that once data is recorded, it cannot be altered without consensus. This creates an immutable record, reducing the risk of fraud and increasing the reliability of the information.
3. Interoperability and standardisation: Many commercial systems are designed to be interoperable with existing enterprise systems and support industry standards. This facilitates easier adoption and allows for seamless data sharing across different platforms and stakeholders.
4. Multi-functionality: blockchain platforms are often designed to go beyond traceability. For example, Mastercard's system incorporates B2B payments and financing, while the Zimbabwe system enables the use of livestock as collateral for loans. This multi-functionality adds significant value for users.
5. Scalability and flexibility: the systems are designed to handle large volumes of data and transactions and can be applied to various industries beyond just food and livestock. This scalability and flexibility make them adaptable to different needs and contexts.

Disadvantages:

1. Implementation complexity and costs: adopting these systems often requires significant changes to existing processes and potentially new hardware (like RFID readers). The initial implementation can be complex and costly, which may be a barrier, especially for smaller businesses.
2. Adoption challenges: for these systems to be truly effective, they require widespread adoption across the supply chain. Getting all stakeholders on board, particularly in fragmented industries, can be challenging.
3. Data input reliability: while blockchain ensures that recorded data cannot be altered, it does not guarantee the accuracy of the initial input. The systems still rely on humans or IoT devices for data entry, which can be sources of error, representing a significant risk. There is a need for a trust management system for evaluating the trustworthiness of data provided by the participants
4. Technological barriers: while designed to be user-friendly, these systems still require a certain level of technological literacy. This could be a barrier in some contexts, particularly in developing regions or among smaller, traditional producers with limited use of modern technology.

4.2.8 Zimbabwe

System overview

E-Livestock Global is a pilot blockchain-based cattle traceability system implemented in Zimbabwe. It was developed by the start-up E-Livestock Global in partnership with Mastercard (currently based on nChain blockchain platform) (E-Livestock Global, 2024).

It aims to empower Zimbabwean farmers to prove the origin and health records of their cattle, while reducing risks to buyers. The ultimate goal is to help Zimbabwe regain its lucrative beef export market and support economic recovery. The system was designed to ensure equal access regardless of remoteness and farm size. It was designed from "bottom up" to ensure small farms (5-6 animals) can gain value from the system: proof of ownership, proof of animal health and allows participation in national system (E-Livestock Global, 2022).

The implementation of this blockchain-based system is limited currently, but demonstrates how advanced technology can be adapted to address specific regional challenges and support economic development in emerging markets. It also showcases the potential of blockchain technology to create transparent, secure, and inclusive systems in the agricultural sector.

Cost structure

Farmers typically pay US$2 for each UHF RFID tag, which can be read via a CSR108 scanner (US$1,000) – although not necessary (E-Livestock Global, 2022).

Commercial farmers also pay US$ 1.00 per annum as access fee for the platform. The first year of usage is free. Variable pay structure for data access – customer can access information for free, or can pay additional premium to access additional information stored on block chain platform (MarichoMedia, 2021).

Main benefits provided

Immutable data records

- System's use of blockchain ensures that records of identity, ownership, livestock information, etc. are immutable
- Provides an irrefutable record of ownership, supports sales and exports, and allows them to use cattle as collateral for loans

Transparency and trust

- The system allows consumers to trace cattle back to its source, providing crucial information for health, social, and environmental considerations
- For producers, it offers detailed post-processing data on their cattle, including pricing and yield

Premium in export markets

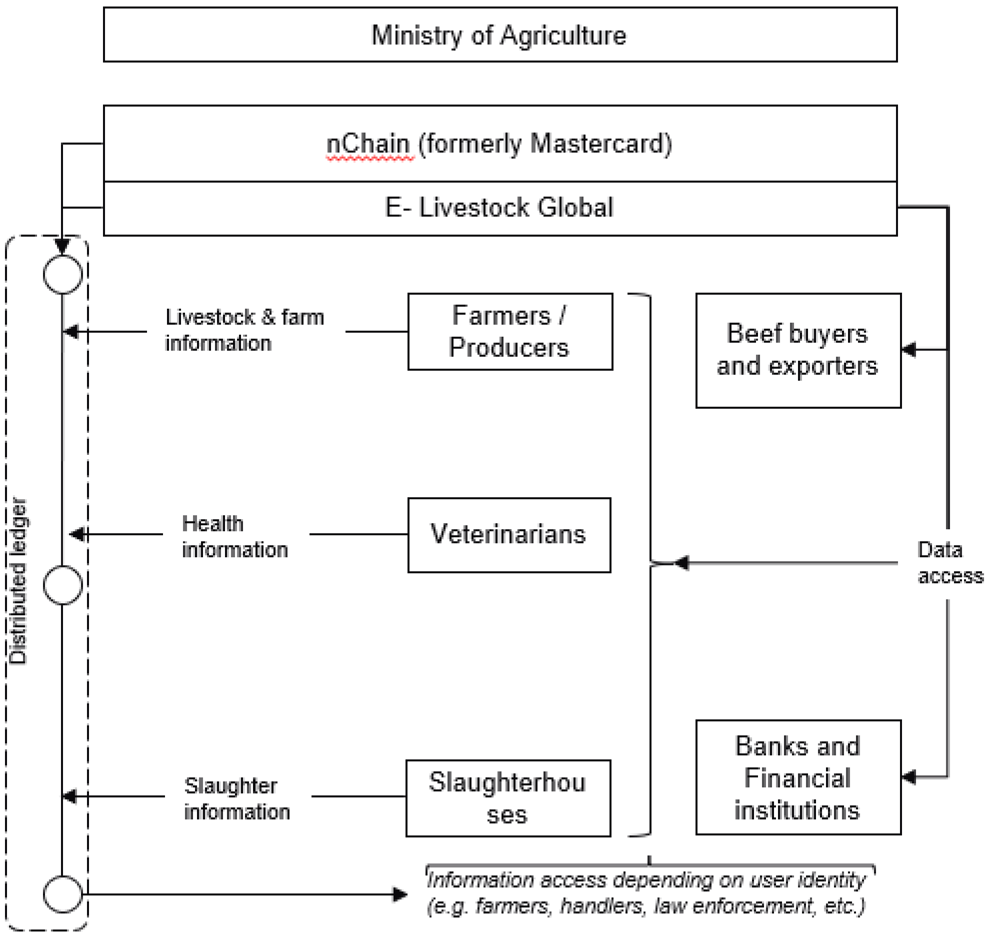
- The system provides detailed information about the origin and history of livestock, ensuring traceability from the field to the slaughterhouse. This is especially important for accessing international markets, where high standards of quality and food safety are required

Ease of access

- The system was designed with smartphone as main point of data input and access – which provides access to farmers of all size and scale
- Modules have been built to cater to specific data users (e.g. dedicated module to allow law enforcers to validate ownership)

Stakeholder roles and responsibilities

Figure 8 Stakeholders involved in Zimbabwe's livestock traceability system



Zimbabwe Ministry of Agriculture:

- Responsible for regulatory oversight
- Responsible for intervention in case of disease outbreak

E-Livestock Global:

- Commercial provider which developed the system
- Responsible for implementation, operation and maintenance of the traceability system

Mastercard/nChain:

- Commercial provider of blockchain-based Provenance solution
- In the future state, blockchain providers can introduce integrated payment systems or marketplace
- Distributed ledger are assigned to individual farmers. Each farmer has a unique identifying hash number. Each farmer entity is associated with ownership of one or several farm 'entities', which individually contains one or several livestock 'entities'

Veterinarians and health workers:

- Record medical treatments and vaccinations in the system

Banks and financial institutions:

- Potential users of the system for verifying cattle as collateral for loans

Beef buyers and exporters:

- Use the system to verify the origin and health status of cattle
- Transfer of ownership done simply by entering blockchain hash number

Other data users: Police can log onto app (not web portal) and put in ID to show name of owner and ID number. Allows law enforcement to contact owner/farmer/who?

Farmers:

- Responsible for tagging animal and updating information into system (individual events/animal information via app or bulk information upload via csv file)
- Relies on system dashboard to manage stock count, verify ownership, confirm purchase weight
- Records information relating to transport, ownership transfer, etc.
- Notified when another user scans their cattle

Multi-criteria assessment

Table 10 Scored multi-criteria assessment result – Zimbabwe

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with value beyond traceability/biosecurity. It supports animal welfare, farm practices, and enables financial inclusion by allowing cattle to be used as collateral for loans. It also has the potential to revitalise Zimbabwe's beef export market. The system is also exploring further utilities (e.g. integration of biometric functionality into the tag)
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	3	The system is specifically designed for livestock traceability, particularly cattle. It's already being applied in this context in Zimbabwe with plans to expand to other African countries.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	M	2	The technology (RFID tags, blockchain, mobile apps) is potentially accessible in the Australian context. However, in Australia, UHF RFID tags are not yet widely used for NLIS purposes, with LF RFID still prevalent and the system would need to transition from a solely cloud-based solution toward incorporating a combination of cloud and distributed ledger technologies.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	2	The system seems relatively easy to adopt, with demonstrated examples in Zimbabwe. However, full-scale adoption in Australia is faced with major challenges including the transition to UHF infrastructure, etc.
5	Cost	Are costs related to a user accessing the system reasonable?	H	3	The cost (USD 2 per tag plus annual fees) seems reasonable, especially considering the potential benefits. It is comparable to the cost of AUD 4 per tag in Australia.
6	Effort	Is the contact time required of a user to engage the system reasonable?	H	2.5	The system requires some user input (tagging animals, recording events), but much of the process is automated once set up. The

					ability to work offline and sync later reduces effort in areas with poor connectivity.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The blockchain-based system seems designed to share data with various stakeholders (farmers, veterinarians, buyers, financial institutions). It can likely receive and output data to other platforms.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	3	The use of blockchain technology provides a high level of data validation. Each event is recorded and verified on the blockchain, creating a tamper-proof record once within the system. This relies on the assumption the data entered in the first instance was true/correct.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	3	The blockchain technology and Mastercard's involvement suggest a high level of data security. The system appears to protect user privacy while still allowing necessary data sharing.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	3	The system's ability to work offline and sync later demonstrates resilience. The use of blockchain technology also provides inherent backup and data integrity features.

Qualitative assessment

Advantages:

1. Comprehensive traceability: The system provides end-to-end visibility of the cattle supply chain, recording every significant event in an animal's life from birth to slaughter. This comprehensive tracking enhances food safety, supports disease control, and could help Zimbabwe regain access to lucrative export markets.
2. Blockchain security: By leveraging blockchain technology, the system ensures data integrity and security. Once recorded, information cannot be altered without consensus, providing a tamper-proof record that can be trusted by all stakeholders.
3. Financial inclusion: The system enables farmers to use their cattle as collateral for loans, potentially opening up new financial opportunities for rural communities. This could have significant socio-economic benefits beyond just improving cattle management for the Zimbabwean agricultural sector. In Australia, this may be a verifiable record of livestock assets for financial records.
4. Offline functionality: The ability to record data offline and sync later is crucial for implementation in rural areas with limited connectivity. This feature enhances the system's usability and adoption potential across diverse geographical areas.
5. Multi-stakeholder benefits: The system provides benefits to various stakeholders along the supply chain, from farmers to buyers to financial institutions. It was designed to be adoptable for farmers of all size/scale and all socio-economic backgrounds. Its core design principle focuses on the use of smartphones as a data recording and data access point, which stems from Zimbabwe's high adoption rate of smartphones.

Disadvantages:

1. Reliance on users: The systems relies on information being added that is accurate in the first instance. It also relies on users that have access to technology and are technologically literate.
2. Dependency on external actors: The system's reliance on Mastercard's blockchain technology and other external stakeholders could create dependencies that might be challenging to manage in the long term, especially if there are changes in partnerships or technologies.
3. Cost to access additional data: In its base form, users can access information stored in cloud server. Users may need to pay additional access fee for specific datapoints stored in the blockchain (although optional). E-Livestock global has designed multiple user constructs (e.g. farm owner, law enforcement, government) to control for appropriate levels of data access – which, in theory, minimises cases where users need to pay to access data.
4. Lack of product traceability: The system currently traces livestock from farm to slaughter. There is no traceability to the carcase or to end products.

4.2.9 GPS/IoT Technologies

System overview

Integrated traceability systems using GPS and/or IoT technologies are advanced tracking solutions designed to monitor goods in real-time, particularly in sectors such as food, pharmaceuticals, agriculture, and retail. These systems typically employ GPS-enabled sensors and other IoT devices to track not only the location of goods but also their condition throughout the supply chain.

Key features of these systems include:

- Real-time location tracking using GPS technology
- Monitoring of environmental conditions (e.g., temperature, humidity) using IoT sensors
- Movement detection and logging
- Integration with existing supply chain management systems

Notable examples of such integrated traceability systems include:

- Maersk's Remote Container Management system: This solution tracks shipping containers globally, providing real-time data on location, temperature, and other relevant conditions. It's particularly useful for monitoring sensitive cargo such as perishable goods.
- Smart Paddock's Bluebell tags: These GPS and IoT-enabled tags are designed for livestock tracking. They provide real-time location data and can monitor animal behaviour and health indicators, offering valuable insights to farmers and supply chain managers.

Cost structure

Hardware costs for integrated GPS and IoT traceability systems vary depending on the provider and the specific technology used. For example:

- Smart Paddock charges $59 per GPS SmartTag, with options to purchase additional IoT sensors (Smart Paddock, 2024)
- Ceres Tag offers a bundle of 24 pieces for $280, providing up to 40% savings compared to individual purchases (Ceres Tag, 2024)

Beyond the hardware costs, implementing these systems typically involves additional expenses:

- Software development and maintenance
- Cloud computing and data storage
- Implementation and staff training

The total cost of ownership for these systems can be significant, especially for large-scale implementations.

Main benefits provided

Real-time monitoring and alerts

- In its most direct application (smart ear tag), the system can provide real-time information about the health (e.g. temperature) and geo-location of all the individual animals in the herd

- Real-time alerts are provided if any metrics significantly change – indicating health issues or animal crossing geo-fences
- Additional equipment can be installed to build an IoT bundle (e.g. electric fence sensor, farm gateway, etc.) to provide even more information

Smart transport tracking and digital mapping

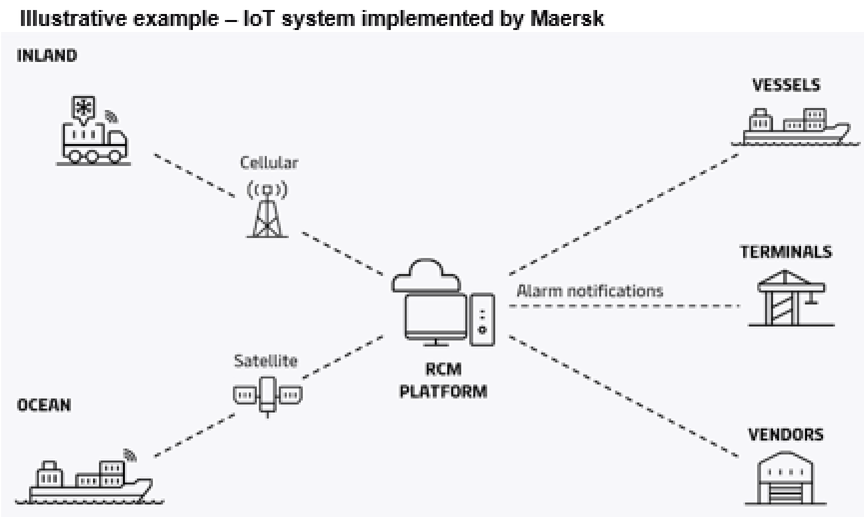
- In fresh supply chains, providers such as FreshChain have provided GS1 Digital Link QR code to create a digital map of produce (e.g. cherries) moving through the supply chain (Freshchain, 2024)
- Other examples include cargo tracking such as Roambee, Logmore, OnAsset – which provide portable cargo monitoring devices which are reusable and travels in delivery truck. They provide real time information on location, temperature, humidity, tilt, etc.

Remote monitoring and control

- In most advanced cases (e.g. Maersk RCM), IoT can be used by users to input commands and directly intervene with the shipping container temperature / humidity to prevent spoilage. This has an added benefit of avoiding additional inspection upon arrival.
- Errors can be alerted in real time and preventative actions can be undertaken remotely, rather than relying on third party to identify and solve the problem

Stakeholder roles and responsibilities

Figure 9 Stakeholders involved in Maersk' Remote Container Management system



Source: Maersk

Government Agencies:

- Regulate developing policies and standards, support implementation, and sometimes fund pilot projects

Technology Providers:

- Companies like IBM, Microsoft, and FreshChain Systems develop, maintain and upgrade the underlying technology platform

Logistics Companies:

- Companies such as Maersk implement the system in their operations (Tata Consultancy Services, 2022)

Farmers/Producers:

- Use the systems to track their products, improve operations thanks to improved monitoring, and provide transparency to consumers. In case of delays or damages the carrier can be held responsible thanks to verified data

Retailers:

- Companies such as Woolworths and Coles implement traceability in their supply chains, providing detailed information to consumers using data from GPS/IoT systems and ensuring quality and safety standards are met.

Users:

- Engage in real-time active monitoring during transportation, with active control on shipment quality and conditions. This allows early intervention in case of emerging issues that are addressed as soon as they emerge thanks to alerts for single users

Inspectors:

- Increased efficiency of checks with lower need of physical intervention, limited to ad-hoc pre-identified cases, with reliance on data collected from GPS IoT systems

Multi-criteria assessment

Table 11 Scored multi-criteria assessment result – GPS/IoT

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with significant value beyond traceability and biosecurity. It provides data on animal welfare, farm practices, and supply chain efficiency, and allows for additional information to be shared with the tag, such as claims and credentials. For food products, it offers insights into freshness and quality. This wide range of applications adds substantial value across the supply chain.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	H	2.5	The system is highly applicable and easily extendable to livestock traceability. It's already being used for cattle and sheep tracking (Smart Paddock), and for tracking various food products. The flexibility of IoT technologies allows for easy adaptation to different livestock and agricultural products.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	M	2	While the technology is readily accessible in many areas, it may require specific infrastructure like IoT sensors, blockchain networks or cloud computing. In remote areas, additional infrastructure (like satellite communication) may be needed. The technology is not universally accessible to all users, especially in remote areas and smaller players.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	2	As GPS/IoT encompasses a broad range of technologies/applications, elements of it could be adopted in different parts of the livestock value chain. Aside from adopting smart ear tags, GPS/IoT solutions may only need to apply to transportation truck to provide real-time location and environmental condition tracking.
5	Cost	Are costs related to a user accessing the system reasonable?	L	0.5	Depending on the design, a number of these systems can be used in conjunction in livestock context – particularly in the transportation phase. GPS/IoT systems tend to require investments in equipment as well as

					access fees for software platform. Use cases in livestock (e.g. smart ear tags) are currently limited, mostly due to price constraints.
6	**Effort**	Is the contact time required of a user to engage the system reasonable?	H	2.5	While many aspects of the system are automated, it still requires significant effort to set up and maintain. Users need to learn new technologies and potentially change existing processes. However, once set up, the day-to-day effort is reduced compared to manual tracking systems.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The system shows high interoperability. It can integrate data from various sources (IoT sensors, blockchain, existing databases) and share data across different platforms. The use of standards like GS1 Digital Link enhances interoperability. Systems like FreshChain demonstrate integration across the entire supply chain.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	H	2.5	The system offers strong validation capabilities. When combined with blockchain technology, it provides immutable records, while IoT sensors offer real-time and third-party validated data. This combination significantly reduces the risk of fraud or errors compared to self-reported systems.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	H	2.5	Security is a key strength of this system. Blockchain technology would provide high data integrity and tamper-resistance. Cloud platforms, alternatively, offer robust security measures. The decentralised nature of data storage in blockchain systems also enhances overall security.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	2.5	The system demonstrates high resilience. Cloud-based storage provides redundancy, while blockchain's distributed nature ensures data persistence. IoT sensors allow for real-time monitoring and quick detection of issues. The system's ability to function offline and sync later also adds to its resilience.

Qualitative assessment

Advantages:

1. Enhanced supply chain visibility: the system provides real-time, end-to-end visibility of products throughout the supply chain. This transparency allows for better decision-making, improved inventory management, and faster response to issues or disruptions.
2. Improved food safety and quality: by tracking environmental conditions and product movement, the system helps ensure food safety and quality. It enables quick identification of potential issues, facilitates efficient recalls, and provides consumers with confidence in the products they purchase.
3. Increased operational efficiency: the automated nature of data collection and analysis reduces manual work, minimises errors, and allows for more efficient resource allocation. For example, in livestock management, it helps in early disease detection and optimizing feeding practices.
4. Strong data integrity and security: the use of blockchain technology ensures that data is tamper-proof and transparent. This builds trust among stakeholders and provides a reliable audit trail for regulatory compliance.
5. Consumer engagement and brand trust: the system allows consumers to access detailed information about products, including origin, production methods, and journey through the supply chain. This transparency can enhance brand trust and potentially command premium prices for products.

Disadvantages:

1. High initial implementation costs: the system requires significant upfront investment in hardware (IoT sensors, tags), software development, and infrastructure. This is a barrier for smaller businesses or those in developing regions.
2. Technical complexity: the integration of multiple technologies (IoT, blockchain, cloud computing) makes the system complex. This complexity could lead to implementation challenges and may require specialised skills for maintenance and troubleshooting. Moreover, the communication and data management demands would be substantial – with the frequency of updates balancing cost efficiency against potential benefits.
3. Data privacy concerns: while the system enhances transparency, it also raises questions about data ownership and privacy. There may be concerns about how much information should be shared and who has access to sensitive business data.
4. Potential for technology dependence: heavy reliance on technology could create vulnerabilities. System failures, connectivity issues, or cyber-attacks could significantly disrupt operations that become dependent on this traceability system.
5. Adoption and integration challenges: implementing this system requires changes to existing processes and potentially to business culture. There may be resistance from stakeholders who are comfortable with traditional methods. Additionally, integrating this system with legacy systems and ensuring adoption across all supply chain partners could be challenging.

4.2.10 Implantable devices

System overview

Implantable biosensors or microchips are advanced technologies used for livestock health monitoring and traceability. These devices are known by various names, including "implantable cardiac monitors," "implantable physiological monitoring devices," and "health microchips."

Implantable devices are designed to continuously monitor various physiological parameters in livestock, including heart rate, body temperature, activity levels, and in some cases, specific biomarkers related to health and fertility (Flávio G. S. et al., 2023).

Many applications, especially in wildlife research, are still in the testing or pilot phase (varying in material composition, fabrication methods). Some versions, particularly for cattle health monitoring, are beginning to see commercial use (e.g. Chordata implantable microchips) (Chordata Insight, 2024).

While much of the research has focused on cattle (both dairy and beef), these systems have been adapted or are being explored for use in other livestock species like sheep, pigs, and poultry, as well as in wildlife research.

Cost structure

Initial cost of implantable devices and associated hardware all depend on provider and features included. There are also typically costs associated with data plans and cloud storage, maintenance and replacement of equipment. Services / implants are provided through commercial providers – with the cost increasingly being borne by farmers and livestock managers as part of their operational expenses.

Main benefits provided

Automated health monitoring

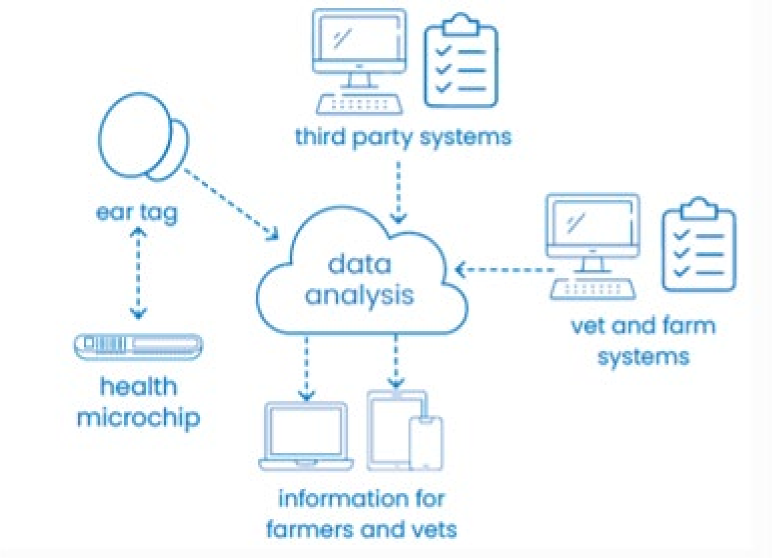
- These systems offer continuous, real-time monitoring without the need for frequent manual checks or blood tests. They can provide early warning of health issues, improve herd management, enhance food safety, and contribute to more sustainable livestock farming practices.
- Access to animal information (incl health data) via scanning at different points in an animal's journey (.e.g. vet check, transport, sale, health/welfare check)

Prevention against tag loss

- Embedded tags can overcome the issue of frequent tag loss / damage and prevent against stock theft.
- Improvement in lifetime retention and traceability can potentially deliver $10m in direct cost to the industry per year (associated with tag replacement) and project against ~$2b in increased biosecurity risks
- However, it takes away the ability to visually identify the animal through tag number and creates a food safety risk as the foreign object would need to be removed at time of slaughter.

Stakeholder roles and responsibilities

Figure 10 Key components of implantable microchip system



Source: The Pearse Lyons Cultivator

Technology Developers/Companies: (e.g., Medtronic, Livestock Labs, Chordata)

- Develop and manufacture the implantable devices and associated technologies
- Provide technical support and ongoing research and development

Research Institutions and Universities:

- Conduct studies on the efficacy and applications of the technology
- Collaborate with companies to improve the systems

Government Agencies: (e.g., Department of Agriculture)

- Regulate the use of these technologies
- Provide funding for research and development
- Set standards for animal traceability and health monitoring

Veterinary Professionals:

- Provide medical care based on the information gathered

Farmers and Livestock Managers:

- Primary end-users of the technology
- Implant the devices and interpret the health data
- Manage the day-to-day use of the system in their herds

Meat and Dairy Industry:

- Benefit from improved traceability and quality assurance
- May invest in or promote the adoption of these technologies

Multi-criteria assessment

Table 12 - Scored multi-criteria assessment result – Implantable devices

No.	Criteria	Definition	Score		Scoring rationale
1	Utility	Does the system generate outputs with potential value beyond traceability /biosecurity (e.g. animal welfare, farm practices, carbon accounting, etc.)?	H	3	The system generates outputs with potential value beyond traceability and biosecurity. It provides data on animal health, fertility, stress levels, and behaviour, which may be used for improving animal welfare, optimising farm management, and enhancing productivity.
2	Extension	For systems applicable to any industry, are they able to be applied, or easily extendable to livestock traceability?	M	2	While initially developed for cattle, the technology has shown great potential for application across various livestock species and even wildlife. It is highly adaptable to different animal types with minimal modifications. However, it is primarily used for health monitoring rather than traceability.
3	Technology	Is the technology required to engage the system readily accessible (for typical users)?	M	2	The technology is readily accessible in developed countries with good infrastructure. However, in remote areas or developing regions, issues with connectivity and power supply might limit its accessibility.
4	Adoptability	Is the system easy for a typical user to adopt and deploy in Australian livestock context?	M	2	Implantable ID devices are still undergoing field trials in the Australian livestock sector. They are likely to be most suitable for early adopters who experience high levels of tag loss, seek to improve welfare and farm management practices, or are affected by stock theft. Food safety and logistic concerns (e.g. device removal at time of slaughter) and insertion difficulties (e.g. rumen bolus) are likely to limit adoption.
5	Cost	Are costs related to a user accessing the system reasonable?	M	1.5	Depending on the desired capabilities of the implantable device, implementation cost may be significant. The decision to implement implantable is only justifiable in extremely premium cattle or done on specifically chosen animals.

6	**Effort**	Is the contact time required of a user to engage the system reasonable?	L	0.5	Once implemented, the system greatly reduces the manual effort required for monitoring animal health. It provides continuous, automated data collection and analysis, saving significant time and labour. However, farmers will need to approach cattle closely to use a device that recognises the implantable ID.
7	**Inter-operability**	Is the system easily able to integrate data from or share data to other systems /platforms?	H	3	The system appears to be designed with integration in mind. It can receive and output data to other platforms, potentially integrating with farm management software, veterinary systems, and industry databases.
8	**Validation**	Is data added to the system self-reported, or third party assessed or validated?	M	2	Data relating to identity is relatively tamper-proof as the device is embedded in the animal. Health data is transmitted directly from the sensors and the accuracy depends on device's inherent precision.
9	**Security**	Does the system store or handle data in a way that assures and protects user's privacy or confidentiality?	M	2	While the sources mention encryption and access controls, the extensive data collection and wireless transmission could potentially pose security risks if not managed properly. More information would be needed to give a higher score.
10	**Resilience**	How reliable is the system and does it have mechanisms in place to ensure data integrity and recovery?	H	2.5	The system appears to have good mechanisms for ensuring data integrity and recovery. With cloud-based storage, and the ability to function offline and sync later, it demonstrates strong resilience and helps avoid tag loss problems.

Qualitative assessment

Advantages:

1. Continuous real-time monitoring: the system allows for constant, real-time monitoring of animal health and behaviour without the need for frequent manual checks or invasive procedures. This enables early detection of health issues and rapid response to potential problems.
2. Improved animal welfare: by providing early warning signs of illness or stress, where there is real time linkage, the system allows for timely interventions, potentially reducing animal suffering and improving overall welfare. It also minimises the need for handling, which can be stressful for animals.
3. Enhanced productivity and efficiency: the system can help optimise feeding, breeding, and general management practices, potentially leading to increased productivity. It can also reduce labour costs associated with manual monitoring and health checks.
4. Tamper-proof alternative to traceability ear tag: as the tags are embedded in the animal tissue, tag loss/damage and stock theft can be minimised.
5. Recent field trials have indicated that qualified vets may not be required to apply the devices.

Disadvantages:

1. Scanners are required to identify livestock and record information.
2. Depending on the type of implantable device implemented, cost could become a limiting factor for mass adoption.
3. Power limitations and potential migration issues with implantable devices. Implantable locations are limited (e.g. behind the ear) and is reliant on animal physical condition (i.e. tissue needs to be free of pre-existing damage and excessive tags) to ensure tag retention. There is also a need for regulation on where they can be inserted and this may not be easily monitored.
4. Scan range be limited due to flesh and/or wool.
5. While the system aims to improve animal welfare, there are concerns about the invasiveness of implantable devices and potential long-term effects on animal health and behaviour. There is also the risk of malfunction or infection at implant sites.
6. Processor’s concerns over potential food safety risks (e.g. device migration creates a challenge in device removal at time of slaughter)is likely to reduce adoptability.

5. Conclusion

5.1 Key findings

Livestock traceability systems play a crucial role in modern agriculture, ensuring food safety, supporting genetic improvement, and enhancing supply chain transparency. Systems in different country markets are often designed and implemented with distinct primary purposes in mind. While some focus on product traceability to enhance consumer confidence and meet regulatory requirements, others prioritise genetic evaluation to improve breeding programs and livestock performance. Effective design of a traceability systems will likely require a combination of existing and emerging technologies.

Ireland

- Designed primarily for the purpose of genotyping the national herd – provides significant benefits to the EBI and aims to extract maximum insights from genetic information (e.g. for valuation purposes).
- Genotyping since birth helps with parentage traceability and provides an identification mechanism for the animal.
- Tagging cost is partially subsidised but requires paid subscription service (e.g. HerdPlus) to extract most value from data.
- Double-tissue tag is used – combining sample collection and tagging process into one.
- Livestock traceability is a secondary benefit, with the primary being genetic evaluation.
- Currently exploring advanced technology implementation, such as blockchain, to enable farm to fork traceability, as well as smart sensors.

Japan

- Designed primarily for the purpose of product traceability and transparency – particularly for Wagyu.
- Extremely stringent and requires all stages of the supply chain (from farm to retail) to track and add to identification number (e.g. carcass ID at slaughterhouse, product ID at retail, etc.) to ensure end-products are traceable to each animal.
- Exhaustively covers all communication channels for data collection (e.g. fax, phone, email, app, etc.) to allow all to participate in data reporting.
- Government support to minimise burden on farmers.
- Limited in automation – with ear tags mostly being visual.
- Limited use of muzzle print in premium Wagyu – provide mainly as a differentiating market factor and not fully utilised for traceability.
- Final product traceability to support premium beef (e.g. Wagyu), benefitting from practices like daily health checks, DNA sampling for post-processing traceability, and breeding, which could be applied to high value breeds (e.g. Wagyu, Angus) in the Australian context.

Uruguay

- One of the first countries to utilise RFID tag to trace livestock with the intention of tracing products from farm to plate.
- Adopts double tag system – both visual and LF RFID.
- System is State-funded, with minimum cost required from farmers.
- Georeferenced records are available.
- Currently exploring advanced technology implementation to support data validation, such as blockchain.

South Korea

- Implements UHF RFID in livestock and performs DNA audits to confirm traceability between products and carcass.
- Implemented in multiple livestock species (cattle, pig, chicken).
- Product traceability is mandated and overseen by government for cattle, sheep and pork, to ensure farm-to-plate traceability.
- Exploring the integration of Bluetooth and blockchain technologies in beef traceability, while researching and testing deep learning models for biometric identification (e.g., Hanwoo model), as well as Researching and testing biometric identification technologies for practical implementation.

Zimbabwe

- Designed to be an easy to access, cost-effective system that can work in economically challenging environments and can be adopted by all farmers regardless of size and scale.
- Relies on UHF RFID for lower tagging cost and smartphone as primary user access point – which is appropriate in the Zimbabwean context where smartphone access is high.
- Adopted blockchain to track minute levels of details – encapsulating livestock identity, ownership, health records, movement, etc. and brings all the inherent benefits of block chain such as security, transparency and efficiency.
- Offline usage is possible, allowing users in remote regions to participate.
- Streamlined operations (e.g. ownership change by simply sending request via app).
- Exploring innovative solutions such as deploying UHF/GPS collar on one designated animal, which can detect near-by herd.
- E-Livestock is willing to expand to other African countries (e.g. Zambia and Mozambique), leveraging Zimbabwe's success story.

Digital ID

- Automation of personal records and paperless ID validation. Streamlined service access (mainly government online services.
- Improved security by minimising paper documentation and relying on decentralised information storage.

- No access fee for end users.
- QR, near field communication, and biometrics technology can all be used as access method.
- Limited evidence of prior testing and usage in livestock traceability, however digital ID could be utilised to streamline digital declaration completion and sign off traceability, speeding some current processes throughout the livestock journey (i.e. eNVD handoff and validation of authority).
- Existing commercially available systems such as Docusign, are able to be utilised for verification in low connectivity or offline scenarios, which could be valuable in farm gate sign off scenarios (e.g. eNVD). Includes capture of digital validation of identity, activity time stamp and location data.

DNA / Genomics

- Wide range of technologies, each designed for a specific purposes (e.g. genetic evaluation, performance prediction, product traceability, parentage confirmation, etc.).
- Strong uptake trend by industry, where genotyping is mainly used for valuation and performance purposes, with traceability value being a secondary benefit.
- Costly and not currently practical to implement at individual animal level for traceability purposes, but potential to look at DNA pooling or mob/flock-based profiling.
- Data is captured in decentralised databases (DNA testing provider's own platforms, manual reports or entered to farm management systems/platforms – it is not currently able to be transferred or captured on NLIS systems.

Blockchain

- Technology that can universally apply in any use case including traceability of livestock or product. However, commercial uptake in Australian livestock traceability has been limited.
- Distributed ledger platform providing transparency, security to enhance consumer trust, traceability and allowing access of information in real time.
- Reliant on commercial technology provider to build and orchestrate the system, and designing the type of data it gathers.
- Potential for the technology to be integrated with extended capabilities (e.g. B2B payments)
- Already adopted and in testing environment by forward-looking country markets (e.g. Zimbabwe) for storing livestock information (identity, movement, ownership, etc.).
- Research on blockchain technology combined with IoT for agrifood applications, developing solutions to address data storage issues without increasing computational power, and designing algorithms for double chain structures to tackle high-cost challenges.

GPS/IoT

- Provides real-time information to support tracking the location of parcel/product/livestock at stages throughout the supply chain.

- Potential rich data which can provide valuable insights on movement, location, environmental conditions, etc. and minimises manual effort in data collection, monitoring and reporting, reducing the potential for data errors in transcription.
- In some cases, provides end users with ability to directly interact with the product being traced to enable preventative actions (e.g. temperature control in food supply chain to avoid mould), or provide an accurate, near real time understanding of location and condition.
- Cost-prohibitive – tags are typically more sophisticated than a basic tag and come at a higher price point. Some systems also required multiple forms of hardware – including sensors, tags and other accessories - in order to be effective.

Implantable Devices

- Solves specific issues with tag damage and tag loss by being embedded in the animal.
- More costly per unit than basic tags, but prices (and device size) and decreasing.
- Mainly developed to provide real-time health monitoring capabilities and thus varies in complexity and cost.
- Evidence of evaluation and use in livestock in other jurisdictions, and active use in some commodities, including equine, sheep and camels.
- Advanced bio-sensors partnering with biotech firms and creation of automated alert systems for health issues detected by the implants.

5.2 Benefits to industry

The findings from this global review of livestock traceability systems offer several significant benefits to the Australian red meat industry:

1. Enhanced traceability capabilities: By adopting best practices identified in other countries, such as the use of UHF RFID tags and scanners for improved read range and blockchain technology for data security, the Australian industry can strengthen its traceability system. This will lead to improved food safety, more efficient disease control, and enhanced market access.
   The implementation of such technologies in the Australian context still faces challenges, including regulatory barriers, technology rollout costs, etc. which need to be validated through field trials before industry-wide adoption can be considered.
2. Increased operational efficiency: The implementation of advanced technologies like GPS/IoT tracking during transport and digital ID systems for streamlining documentation processes can significantly reduce manual effort and paperwork. This will result in time and cost savings across the supply chain.
3. Improved animal welfare monitoring: Real-time tracking and health monitoring systems, as seen in some of the reviewed systems, can enable early detection of health issues and stress in animals during transport and on farms. This can lead to better animal welfare outcomes and potentially higher quality products.
4. Enhanced market differentiation: Advanced traceability systems can provide detailed information about the origin, breeding, and lifecycle of animals. This transparency can be leveraged to differentiate Australian red meat in global markets, potentially commanding premium prices for high-quality, ethically produced products.

5. Better data utilisation: The integration of various data sources, as seen in systems like Ireland's, can provide valuable insights for genetic improvement, farm management, and industry-wide decision-making. This can lead to long-term improvements in productivity and sustainability.
6. Increased consumer trust: Comprehensive traceability systems that provide farm-to-plate visibility can enhance consumer confidence in Australian red meat products, both domestically and internationally.
7. Improved biosecurity measures: Advanced traceability systems can enable faster and more accurate responses to disease outbreaks, minimizing economic losses and protecting Australia's reputation as a safe food producer.

By implementing these insights, the Australian red meat industry can maintain its global leadership in livestock traceability, adapt to evolving regulatory requirements, and meet changing consumer demands for transparency and sustainability.

6. Future research and recommendations

6.1 Key recommendations

This project has identified several key challenges and successes that can inform future investments in the Australian livestock traceability systems. The following recommendations are based on the findings and the potential future concepts illustrated in the provided diagrams.

Recommendation 1: Consider the combination of smart phone, GPS/GIS, UHF RFID and IoT technologies – working in combination to enhance the user experience of the traceability system; create more real-time location and traceability data; and address gaps in traceability knowledge.

This could involve adopting a system similar to the one described in Concept 1 (described in section 8.2), where a designated "sentinel" animal is equipped with a UHF-scanning collar capable of detecting nearby cattle with UHF RFID tags. This approach would provide real-time insights into herd behaviour, health, and location. The system should be designed with a user-friendly interface, using smartphones as the primary information delivery channel to reduce the need for specialised equipment. Additionally, implement GPS/IoT trackers during livestock transport, as outlined in Concept 2, to address the current gap in real-time monitoring during transit. This combination of technologies would significantly improve the overall traceability from farm to plate, enhance animal welfare monitoring, and increase operational efficiency throughout the supply chain.

Recommendation 2: Develop a comprehensive strategy to integrate valuable livestock data from third-party systems with the NLIS to enhance the overall traceability ecosystem beyond core NLIS functionality.

Many data points of value to livestock traceability are currently captured by farmers and supply chains in third party databases and systems outside of the NLIS. Most of these do not currently integrate to the NLIS to enable information to be uploaded directly, meaning valuable information on livestock numbers, health, genomics and transportation is potentially missed or not transcribed into the NLIS system. Easing the integration of data from third party sources such as farm management platforms directly to the NLIS could enable new efficiencies and boost traceability, by enhancing the quantity, speed and accuracy of data contributed to the NLIS.

Recommendation 3: Researching the potential of digital ID systems to streamline documentation processes in the supply chain and consider how blockchain is applicable to organising data and data access in the Australian system.

Modernise the documentation process, particularly the National Vendor Declaration (NVD) system, by implementing Digital ID technology as described in Concept 3. This would replace the current paper-based system with a more efficient digital process that can function offline, crucial for areas with limited connectivity. The Digital ID system would allow for pre-validation of individuals' identities, reduce administrative burden, minimise errors, and create a comprehensive digital record of livestock movements and transactions. In parallel, research the integration of blockchain technology to organise and secure this data. As demonstrated by systems in countries like Zimbabwe and Uruguay, blockchain can provide immutable records of livestock identity, ownership, health records, and movements.

Recommendation 4: Consider how an increasing use of tissue sampling and genomic testing in Australian could integrate or be accessible to traceability systems.

Drawing from Ireland's experience with the National Genotyping Programme, consider implementing a system where DNA samples which have been collected from animals either at birth, or during tagging can be easily integrated to the national traceability database. The genomic data contributed to the database could then be used to further enhance traceability by providing access to a unique genetic identifier for the animal. While individual animal testing may be cost-prohibitive for the entire national herd, investigation of the potential applications of DNA pooling or flock profiling techniques is encouraged, to cost-effectively enable the creation of genetic profiles for herds or flocks. Integration of this additional data into the national traceability database, could significantly enhance the potential value of the traceability system, supporting not only traceability but also providing a centralised platform for access to, and verification of genetic information on an animal for use in genetic improvement, disease resistance research, and product quality assurance. This information is currently housed in proprietary systems and not easily accessed by the supply chain or consumers.

6.2 Future traceability system concepts

To tackle challenges faced by the Australian livestock traceability system, including real-time traceability, limited geo-referenced records and manual paperwork, a number of conceptual designs have been proposed. These draw inspirations from expert interviews in country markets such as Zimbabwe, and from innovative use cases of technology to trace commodities and goods in other industries.

Concept 1: Real-time location traceability at the farm

Figure 11 Future concept: using GPS/UHF collar on designated farm animal

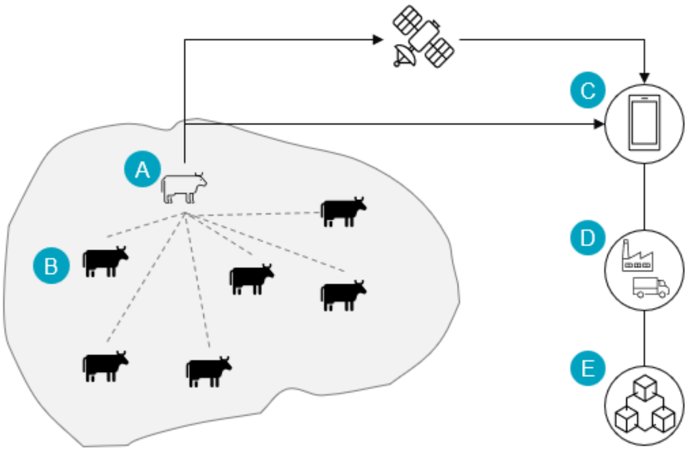


Figure 11 illustrates an innovative approach to livestock traceability that combines several advanced technologies to enhance monitoring and data collection efficiency. The system described offers numerous benefits for farm management, animal health, and supply chain transparency.

The cornerstone of this system is the use of a designated "sentinel" animal equipped with a UHF-scanning collar (A). This collar has the capability to detect and record the presence of nearby cattle, effectively monitoring the entire herd. The remaining animals in the herd are tagged with standard UHF RFID tags, allowing for individual identification when in range of the sentinel animal's collar (B).

This approach enables comprehensive tracking of herd identity, location, and movement patterns. The data collected by the sentinel animal's collar is relayed to the farmer (C), providing real-time insights into herd behaviour and health. By leveraging GPS technology, the system can accurately record geolocation data, linking animal health information to specific locations on the farm.

One of the key advantages of this system is its user-friendly design. The interface follows human-centric principles, with smartphones serving as the primary delivery channel for information. This design choice significantly reduces the need for specialised scanning equipment and enhances ease of access for farmers and other stakeholders.

The system's utility extends beyond basic tracking. It can be used by various stakeholders, including abattoirs, transport operators, and cattle buyers, to quickly access crucial information about the animals (D). This feature streamlines processes throughout the supply chain and enhances overall efficiency.

Furthermore, the incorporation of blockchain technology adds an extra layer of security and transparency to the data management process (E). By automating data entry, validation, and authentication processes, the system minimises the risk of errors and fraud. This not only improves the reliability of the traceability data but also enhances the ability to manage disease outbreaks effectively.

In summary, this innovative traceability system represents a significant advancement in livestock management. By combining UHF RFID technology, GPS tracking, smartphone accessibility, and blockchain security, it offers a comprehensive solution that addresses many of the challenges faced in traditional livestock traceability systems.

Concept 2: Real-time location traceability during livestock transport

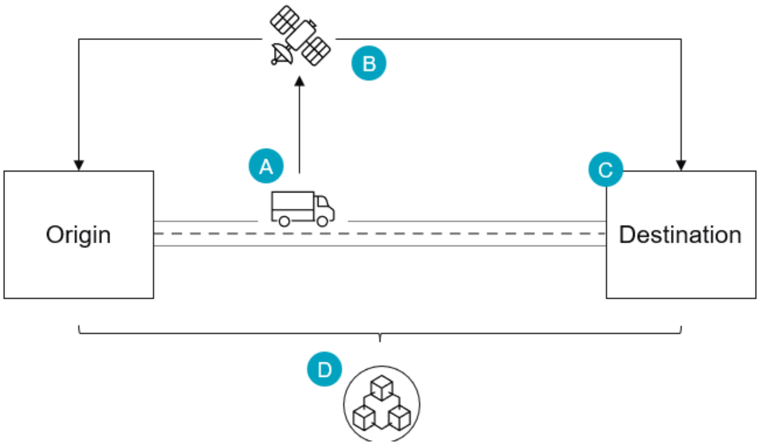


Figure 12 Future concept: using GPS/IoT technology to track cattle location and condition during transport

Figure 12 outlines a proposed upgrade to Australia's livestock traceability infrastructure, specifically targeting the transportation phase. The concept aims to address current system limitations and introduce several improvements for the industry.

At present, Australia's livestock traceability framework provides information on the starting point and final destination of animals but lacks real-time monitoring capabilities during transit. This creates a significant gap in the traceability chain, hindering the ability to track livestock whereabouts and conditions while on the move.

The suggested enhancement involves deploying a mobile, reusable GPS/IoT tracker that accompanies livestock shipments (A). This device would continuously capture and transmit data on the vehicle's position, route, journey duration, ambient temperature, and other relevant environmental metrics (B). The approach draws inspiration from successful implementations in related sectors, such as temperature-controlled logistics and pharmaceutical supply chains.

This upgraded tracking mechanism offers multiple benefits. It provides uninterrupted visibility of livestock movements from origin to destination, closing the existing gap in real-time monitoring during transport. Beyond improving traceability, this continuous oversight yields valuable insights into animal welfare conditions throughout the journey.

Furthermore, the system allows various stakeholders – including transporters, buyers, and regulatory bodies – to monitor shipments in real-time and take prompt action if needed (C). This feature is particularly crucial for managing disease outbreaks or other urgent situations, enabling rapid response and potentially containing health risks.

An additional advantage is the potential to streamline inspection procedures upon arrival. Continuous monitoring throughout the journey can provide assurance about transit conditions, possibly reducing the need for extensive checks at the destination.

Finally, the detailed journey logs generated by this system can be integrated into individual animal records, enhancing the overall traceability framework and providing a rich dataset for future analysis and reference (D).

In essence, this proposed upgrade addresses a critical weakness in the current Australian livestock traceability system. By implementing comprehensive real-time tracking during transport, it promises to enhance animal welfare, bolster disease management capabilities, and boost overall efficiency in the livestock supply chain.

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