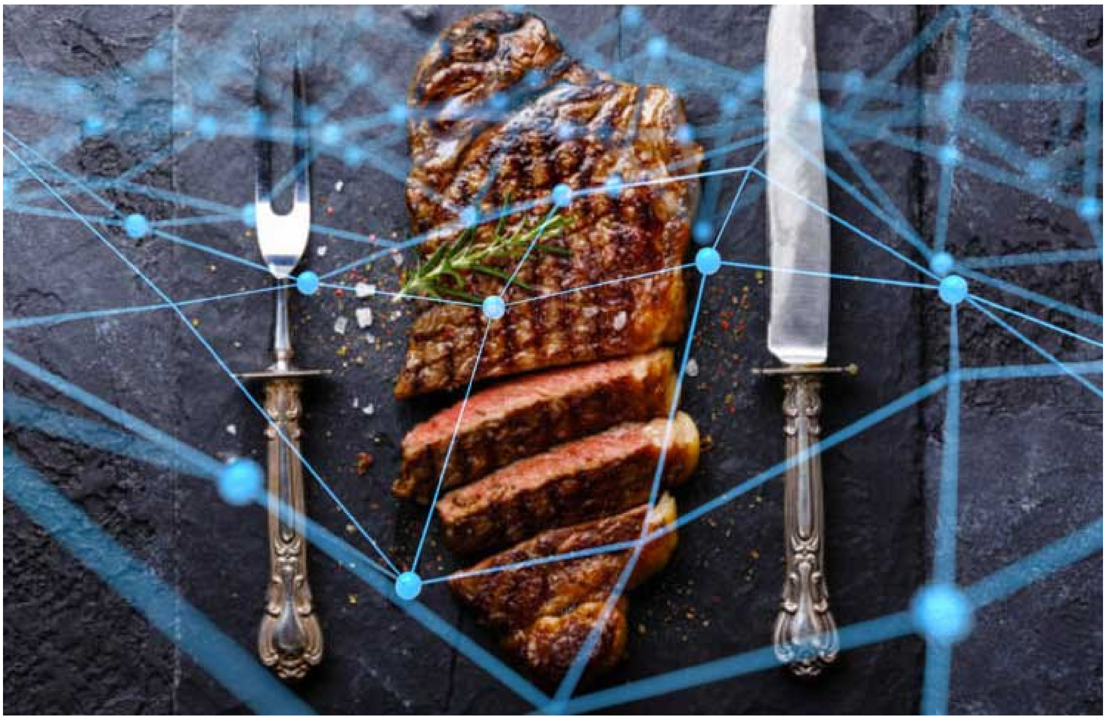

Red meat traceability with Blockchain: Pasture to Plate or Pie in the Sky?

Kellogg Rural Leadership Programme

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William Halliday

I wish to thank the Kellogg Programme Investing Partners
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EXECUTIVE SUMMARY

New Zealand's agricultural industry has a reputation for being at the forefront of technological innovation. Challenges such as nutrient deficient soils and distance to market have been met with novel fertilisers and refrigerated shipping. World renowned animal welfare standards and freedom from significant agricultural pests and diseases give our farmers significant advantages compared to their overseas counterparts. It may be a surprise to learn, therefore, that the means of certifying products and providing assurance to global markets continues to rely on a paper-based system.

Importers must trust the paperwork provided by the exporter. Exporters must trust the paperwork provided by the producer. Producers must trust the paperwork provided by the supplier, and so on. This "one up, one down" traceability is becoming less acceptable to the global market, especially when it comes to food safety and claims of provenance.

A potential solution is to adopt blockchain technology, where a decentralised ledger allows supply-chain-wide visibility of product flows and immutable proof of claims. While blockchain was developed for, and is still chiefly used in, the field of cryptocurrencies, it has found utility in other sectors including finance and supply chain management. The global diamond trade demands absolute proof of provenance to avoid stones mined using forced labour or where proceeds fund violence – it has found a solution to this using blockchain.

Blockchain has become a technological buzzword which has garnered plenty of attention, confusion, and misunderstanding. The purpose of this research report is to understand what a blockchain is, what it can (and cannot) do, what barriers exist to its adoption in red meat traceability, and what opportunities it presents.

Analysis of the literature and interviews with industry stakeholders leads to the general conclusion that while blockchain has some significant advantages over traditional, centralised databases, there is doubt as its maturity as a technology. This represents significant risk to those interested in adopting it, and, coupled with the cost of replacing or upgrading systems across the supply chain, it is widely held that existing systems are fit for purpose and to make a shift to blockchain would represent an unnecessary disruption to the industry.

That said, there are potential drivers for blockchain adoption to consider. Government regulations regarding food safety and animal traceability are updated continually and can require the adoption of new technologies (the NAIT Act 2012 for example). Import requirements are subject to change, especially in the face of food fraud and the global spread of animal and human diseases. Then there is the industry itself, which has an impressive track record of adopting and adapting technologies for the improvement of sustainability and productivity. The convergence of blockchain with technologies such as the Internet of Things and machine learning could change the way farmers go about their business altogether.

It is therefore recommended that stakeholders in the New Zealand red meat sector keep an open mind to the possibility of adopting blockchain technology and be prepared to invest in further technological innovation as more demands are placed on existing systems. Being "blockchain-ready" will undoubtedly leave the sector better prepared for the future of global red-meat trade.

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1. INTRODUCTION

On 3 January 2009 the first Bitcoin was created on a virtual “block” of computer code, in an openly viewable digital ledger. As new bitcoins were created and traded, new blocks were added to create a chain. By 2016 the chain had grown to over 50GB, and the name “blockchain” became common parlance for open-source distributed ledger technology.

Myriad applications for the technology have since emerged. Blockchains can now be found across a growing number of industries worldwide, with supply chains particularly suited to their application. Industries such as gaming, mining, fashion, and music have adopted distributed ledger technology as a secure and immutable record of provenance, ownership, inventory, and traceability. Each participant in the supply chain can have complete confidence that claims associated with a product are true and verifiable thanks to an unbroken chain of auditable information. One can purchase a diamond, for example, along with an immutable digital record of its origin and all its previous owners (Williams, 2020; Nash, 2016). Because of its diverse functionality, blockchain technology has been labelled a disruptive innovation, a technological revolution, or even “the most important invention since the internet” (Jenkinson, 2018).

Where, then, are the blockchains that provide evidence of the sustainability, safety, and provenance of New Zealand red meat?

It is common knowledge that the ability to authenticate and certify red meat products is crucial to maintaining and growing our global market share (NZFAP, 2021; Proudfoot and Keeys, 2021). While current systems appear to be adequately serving the sector, there is unease among some participants that by failing to investigate and adopt new technology New Zealand risks surrendering market access to its competitors. Chairman of Trust Alliance NZ Chris Claridge goes as far as to suggest that “lack of understanding of digital technologies is currently the biggest threat to New Zealand’s primary industries” (C. Claridge, personal communication, 12 May 2022).

Additionally, “food fraud” has become big business in some parts of the world, costing an estimated AU$40-50 billion (approx NZ$44-55 billion) per year globally (Smith et. al. 2021). Blockchain has been suggested as a potential solution (Dalton et. al. 2018) or at least a part thereof (Smith et. al. 2021).

Overseas start-ups have been recording agricultural data on blockchains since 2016 (TE-FOOD, 2022), and shipments of blockchain-traced beef have been sent from Australia to China in 2018 (Nason, 2022) and from the USA to Taiwan in 2019 (Northern AG Network, 2019). The maturity of the platform remains in question, however, with the industry at large currently slow to adopt it.

This research project aims to understand the benefits, drawbacks, drivers, and barriers to blockchain adoption in NZ red meat supply chains, and in doing so answer the question: is blockchain the true path to the dream of Paddock to Plate traceability?

2. AIMS AND OBJECTIVES

The objectives of this research project are to:

1. Understand what blockchain is, its benefits, and its limitations.
2. Determine how blockchain could fit into the New Zealand red meat sector.
3. Identify the drivers and barriers to the adoption of the technology for the red meat sector.
4. Examine how the convergence of blockchain and other emerging technologies might help shape the future of red meat supply chains.

3. METHODOLOGY

The investigative approach undertaken for this report included a literature review followed by semi-structured interviews with red meat industry stakeholders.

The literature review combined information from a variety of sources, including published books, peer-reviewed papers, government publications, industry organisation publications, news articles, websites, and a television documentary. Limitations to the review arise from the relative lack of peer-reviewed, subject-specific literature, requiring the author to draw conclusions from a limited pool of verifiable, high-quality information.

Interviews were conducted in such a way that key themes were explored, and positions explained by interviewees in their own words. The interviews were therefore conversational in nature so that new concepts or information could be further explored, while maintaining a loose adherence to the list of key questions. Interviewees included representatives of five New Zealand meat companies, OSPRI, AsureQuality, the Ministry for Primary Industries (MPI), Beef + Lamb New Zealand, Meat and Livestock Australia, Trust Alliance NZ, Flying Diamond Beef (USA), and technology company Spark 64. Limitations to this approach arose due to the extreme variability of interviewees' understanding of the subject matter and conflict between personal and professional judgement of the technology's potential.

Information from the interviews was collated, compared, and used to test initial conclusions formed from the literature review. Agreements and disagreements were noted and used to form the body of this report's discussion.

4. WHAT IS BLOCKCHAIN?

4.1 Decentralised ledger technology

A blockchain is a method of recording and storing information in a digital ledger. The fundamental difference between a blockchain and a standard database is that instead of storing information centrally it is distributed (decentralised) between all participants (nodes) in a computer network, with each network participant holding a complete copy of the ledger. The addition of new information to the ledger can only occur through consensus among network participants. Data are packaged together into a “block” which is timestamped and cryptographically linked to the previous block, thereby creating an unbreakable chain of information whose validity is agreed upon by all participants (OPSS, 2020).

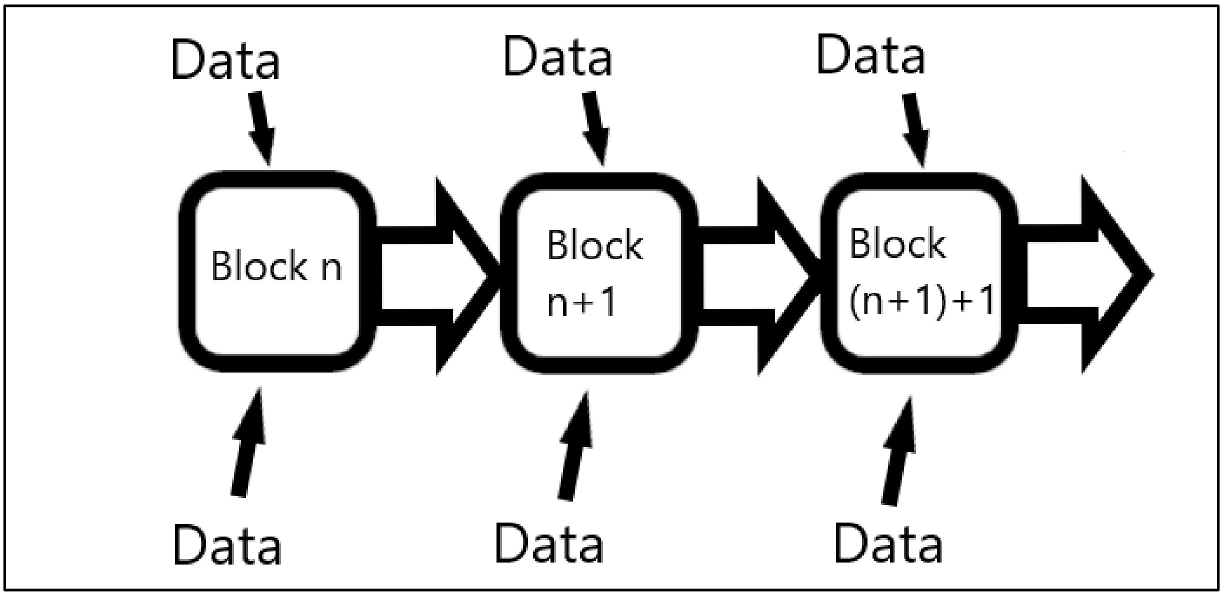

Figure 1: basic structure of a blockchain

The first and most widely known decentralised blockchain is the public ledger for all transactions of the cryptocurrency Bitcoin. The nature of the information that can be recorded on a blockchain is essentially unlimited, however. Examples of red meat production information that could be recorded on a blockchain include:

- Farm of origin data including location and ownership
- Animal attributes such as date of birth, parentage, ID, health, and treatment records
- Transactional records such as purchases and sales of animals, equipment, or consumables
- Product traceability data such as carton identification, manufacturing information, product claims, shipping documents, and food safety information.

The key characteristics of any blockchain are summarised in figure 2.

Key characteristics of Blockchains

Decentralisation

Information is not controlled by any single party. Every participant has access to the entire ledger and its complete history. Anyone can verify the records of their transaction partners directly, without third-party involvement.

Peer-to-Peer networking

Participants on the network can communicate information directly, without the need for a central administrator.

Transparency (with or without anonymity)

Every transaction and its associated attributes are visible to all network participants. Network participants can choose to be identifiable or anonymous.

Immutability of records

Once a transaction is entered in the database and the record updated, it cannot be altered because it is cryptographically linked to every previous transaction, on every participant's copy of the ledger. Such consensus-based recording renders blockchains almost impervious to fraud, because in order to falsify records a hacker would have to alter every copy of the ledger at once.

Computational Logic

Transactions recorded on a blockchain can be integrated with computational logic and programmed by users. These "smart contracts" can automatically trigger subsequent events (for example a payment from one user to another) when pre-agreed conditions are met.

Figure 2: key characteristics of blockchains. Modified from Casey and Wong (2017).

4.2 Traditional Databases

The blockchain concept is a radical departure from the traditional database to which most people are accustomed. Rather than offering open access to information, a traditional database is a centralised data storage construct where access is limited to a privileged few. Crucially for supply chains, visibility is often limited between stakeholders, with most constrained to a "one-up, one down[1]" view of the flow of goods (Kamath, 2020). The flow of information therefore relies on a third-party intermediary, which may be slow and unreliable. This may be considered unacceptable in the case of, say, a contaminated food recall.

Another weakness of the centralised database is that it represents a single point of failure. Whereas a blockchain has, by design, multiple identical copies of the ledger in existence, a centralised database requires attention to ensure data integrity and limit corruption, as well as backup strategies to protect against data loss (Tucker, 2022).

[1] OUOD – where a supply chain participant has visibility of only one link either side of them

Traditional databases do, however, have some advantages over blockchains. A major benefit is the ability to correct errors once they are written to the ledger. While the immutability of records is seen as a key advantage of blockchain, it is entirely dependent on the quality of data entered. It has been widely commented that the NAIT system has not performed optimally since its inception: for example, during the early stages of the *Mycoplasma bovis* outbreak, a survey of 150 farms found only one farm with 100% accurate records (Taunton, 2019). However, the structure of the NAIT database allows records to be easily edited online or via a phone call. If the database was held purely on a blockchain this would be far more difficult.

Furthermore, the traditional database is the established norm, with familiarity among users and established service providers. This is discussed further in section 6.

4.3 Types of blockchains

Naturally, there are variations to the characteristics described in figure 2. Some blockchains, for example the Bitcoin blockchain, are openly visible to anyone with an internet connection. Furthermore, anybody can act as a validator of information and participate in transactions. At the other end of the scale are private or permissioned blockchains, which can only be joined by invitation from a network administrator. The term Distributed Ledger is often used to distinguish private blockchains from truly permissionless, public blockchains (Marvin, 2017).

A recent development is the consortium blockchain[2], which allows for specific data to be visible by permission either with consortium members or publicly (Banerjee, 2022). Utilising such a system, transactional information between businesses can remain private, while maintaining visibility of product traceability. For example, a customer can trace a lamb chop to its farm of origin but does not have permission to view the details of the farmer's confidential supply contracts.

The consortium model most closely resembles the structure of NAIT, where a central authority that is owned by the beneficiaries of the database (OSPRI[3]) provides permissioned access to data while assuring its privacy. It is likely to be the most palatable type of blockchain for red meat producers, as it allows the sharing of relevant supply chain information while maintaining the confidentiality of commercially sensitive data (Tucker, 2022).

4.4 Digitisation

The National Animal Identification and Tracing (NAIT) system currently records cattle and deer using a unique 15-digit numerical identifier. Using this tag number animals are linked to a "person in charge" (PIC). Changes in animal ownership result in a change of PIC which is reflected in the NAIT database by transferring tag numbers between user accounts.

Blockchain technology can take these basic operations further. Creating a record of an animal on a blockchain requires the creation of a digital copy of it (Pyliandis, et.al. 2021). This "digital twin" is a representation of the animal that can include attributes such as date of birth, breed, sex, vaccination records, organic certification, and so on. In the past this information may have been held in paper form or in a computer spreadsheet, however utilising blockchain each digital record is its own

[2] Sometimes referred to as a hybrid or federated blockchain
[3] Operating Solutions for Primary Industries

discrete entity as opposed to a line entry. Each digital animal is kept in a digital "wallet[4]" which is protected by a password or other authentication security measures. Because the wallet and its contents are connected to the blockchain, the attributes attached to each animal are permanent. The result of this is an immutable record of every recorded event in the animal's life, that is linked to the animal whenever it changes ownership.

Real world examples already exist. Jaclyn Wilson of Flying Diamond Ranch in Nebraska, USA, undertook a trial in collaboration with CattleProof[5], Plainsight[6], and Bulla Network[7] in 2021. The trial involved implanting sensors[8] in the necks of Red Angus steers and creating digital representations of the animals in the form of Non-Fungible Tokens (NFTs – see sidebar, right) (J. Wilson, personal communication, 28 May 2022). In this example, each steer was assigned five NFTs: one for the live animal and one for each quarter of beef once the animal was butchered. Once the NFTs were created they were placed in the ranch's digital wallet, thereby establishing proof of ownership (Bulla Network, 2022). The rancher then has exclusive rights to update information to the NFTs such as veterinary treatments or photos. If the steers are sold then their NFTs – and all control rights to the data - are transferred to the new owner (Wolf, 2022).

Non-Fungible Tokens

A non-fungible token (NFT) is a uniquely identifiable digital data file stored on a blockchain. The data recorded in an NFT can include almost anything, including text, photos, video, and audio. The attribute of non-fungibility means that NFTs cannot be duplicated and therefore can only belong to one owner. This differentiates NFTs from cryptocurrencies, which by definition are fungible, meaning the attributes of one unit of are equal to that of any other unit.

Along with the traceability advantages associated with the digitisation of the steers, their presence on the blockchain meant that transfer of ownership could be facilitated using smart contracts. Jaclyn could, for example, sell a steer to another rancher, and when the NFT is transferred to the new owner's wallet a smart contract automatically triggers payment for the animal.

Advancements in sensing technology allow the recording of data related to a growing number of characteristics for farms, animals, cartons of meat, and more. The application of machine learning and artificial intelligence can make use of this information for enhanced decision making and improved efficiency. These topics are discussed further in section 8.

[4] Sometimes referred to as a vault
[5] https://www.cattleproof.com/
[6] https://plainsight.ai/
[7] https://www.bulla.network/
[8] More on this in Section 8: Convergent Technologies

5. HOW COULD BLOCKCHAIN BE APPLIED TO RED MEAT SUPPLY CHAINS?

The underlying technology of blockchain exists and has been tested in different situations, and there appear to be several potential benefits to its adoption in the New Zealand red meat supply chain. This section discusses what that adoption might involve.

5.1 Supply chain overview

To understand how blockchain could be applied to red meat production it is useful to review how the supply chain functions in the New Zealand context. The following is a high-level description of flows within the supply chain – in reality no two business relationships or contracts are the same.

Calves are born on beef and dairy farms. Those born on beef farms are typically weaned from their mothers at around nine months of age, and either fattened (finished) on the home farm or sold to another farm for finishing. Calves born on dairy farms either become dairy cows (on the home farm or sold to another dairy farm), enter the beef supply chain as veal (bobby calves), are sold to a calf-rearing operator (who sells them on at weaning), or are sold directly to a beef finishing farm. Therefore, from the time a calf is born until the time it is slaughtered as an adult, it may have passed through several owners and been aggregated with or separated from other cattle several times. This is especially true for dairy cows that can be transported long distances and added into new herds as sharemilkers take on new contracts.

Sheep tend to have a relatively shorter and more simple supply chain. Lambs not kept as breeding replacements are either sold in batches for slaughter as they reach a target weight or are sold to a finishing farm. Breeding ewes are occasionally traded between farms. Overall, it is uncommon for sheep to have more than two owners throughout their lives.

Following slaughter, carcases are either exported whole or broken down into various cuts of meat. Depending on the cut it may be packaged separately (for example beef tenderloin, rump, leg roast, or lamb rack) or may be aggregated into a carton with cuts from other carcases (for example neck chops, flaps, chuck, or mince). Some meat companies undertake further processing into products such as burger patties, jerky, or microwave-ready meals.

After processing and packaging, cuts and cartons are consolidated into consignments for shipping. Depending on the product and the contract, the meat may pass through a wholesaler and distribution chain to a retailer, restaurant, or secondary processor, before ultimately arriving on the consumer's plate. Variations to this model exist, where there may be direct-to-consumer or direct-to-restaurant shipping, for example, but this is the general model applicable to most red meat from New Zealand.

From these descriptions we can see how quickly the supply chain becomes quite complex, but also begin to identify the parts of the supply chain where it is relatively easy to maintain complete traceability of a meat product from birth to consumption. In theory it should be a simple matter to follow the life of an animal from birth to slaughter using existing technology and utilise a blockchain for proof of authenticity. Likewise, the traceability of a carton of meat or a leg of lamb is currently achievable through barcodes, QR codes[9], or even RFID[10] transponders applied to the packaging (Kirkness, 2019).

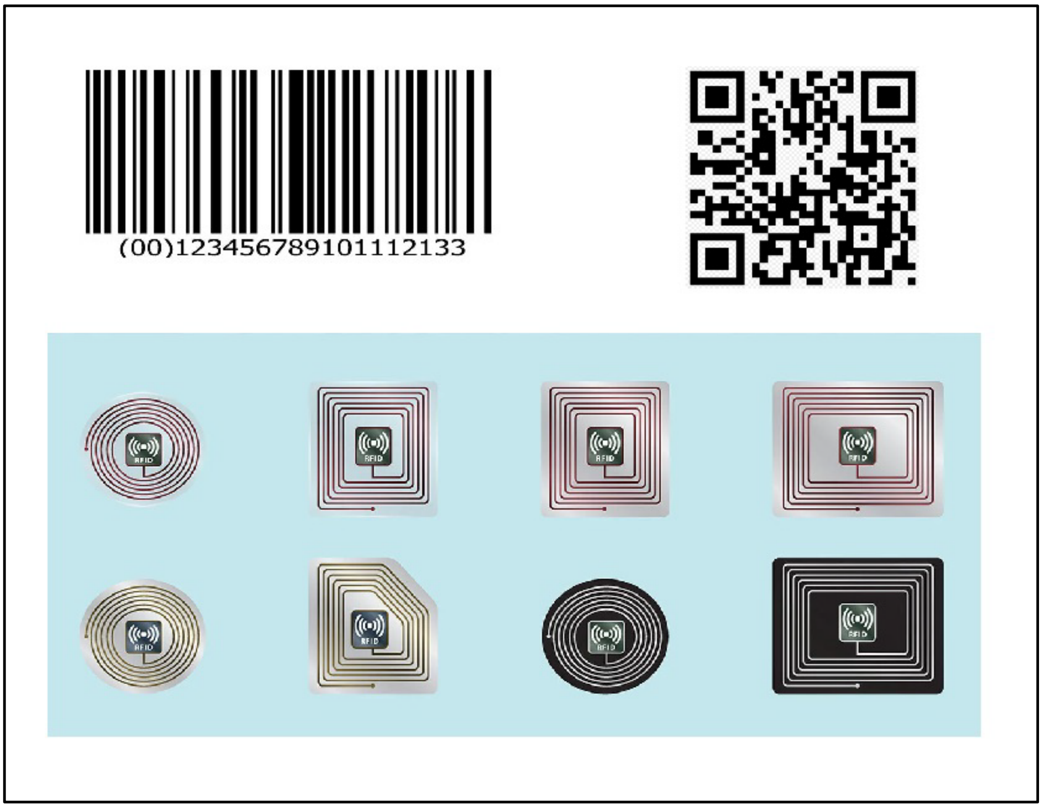

Figure 3: barcode (top left), QR code (top right), and a selection of RFID transponders (bottom)

Where current systems struggle to maintain traceability, however, is during the transition from a carcase to a collection of cuts. A carton of neck chops, for example, will contain parts from potentially dozens of lambs which may have originated from different farms or even regions. The outcome of this is that true "pasture to plate" traceability is realistically achievable only for individually packaged cuts of meat. As these tend to be the higher value cuts, they are where the premium value of complete traceability is generally expected to lie (H. Good, personal communication, 23 Feb 2022[11]).

From this analysis three areas for blockchain application can be identified:

1. Whole of life animal traceability
2. Processor to consumer traceability for red meat
3. Animal to consumer (pasture to plate) traceability for prime cuts

5.2 Whole of life animal traceability

The ability to trace an animal's entire life from birth to slaughter has multiple benefits. The most demonstrably valuable benefit from a New Zealand perspective is traceability for biosecurity and disease control. The not-for-profit company OSPRI was created for the purpose of eliminating Bovine

[9] Quick Response code – a two-dimensional matrix barcode invented in 1994 by Masahiro Hara
[10] Radio Frequency Identification
[11] Hugh Good, Global Market Intelligence and Research Manager, Beef + Lamb New Zealand

TB from New Zealand, partly by managing the NAIT scheme (Tucker, 2022). Bovine TB has been reduced in prevalence from 666 infected herds in June 2000 to fewer than 20 today, with a target of zero infected herds by 2026[12], chiefly due to the ability of authorities to trace animal movements through the AHB[13] numbers printed on ear tags and, latterly, NAIT-registered RFID ear tags. The programme to eliminate *Mycoplasma bovis* has seen similar success which would have been unlikely without the NAIT scheme (A. Barclay, personal communication, 30 June 2021[14]).

Another major benefit of animal traceability is the ability to verify claims relating to animal welfare and food safety, as well as special claims such as "organic" or "antibiotic free". Such claims currently rely on paper-based verification and auditing systems and are not linked to NAIT. It must therefore be taken on trust that suppliers maintain true and accurate records, and that the processor maintains the chain of traceability throughout the butchering, packaging, and distribution processes.

The inherent properties of transparency and immutability possessed by blockchain therefore appear well-suited to a livestock traceability scheme, from the viewpoint of the producer, the processor, and the regulator. Complete digitisation of records on a permissioned or consortium blockchain would allow instant traceability of animals and their attributes between farms, transporters, and slaughter plants. Meat companies could have confidence that the claims printed on food labels (such as "grass fed" or "organic") are backed up by an unbreakable chain of evidence back in time to the birth of the animal. With the added functionality of smart contracts, payments for the trading, transportation, and slaughter of livestock can be made instantly based upon pre-agreed conditions.

However, despite the benefits that blockchain could provide to animal traceability, adoption has been slow globally. Several trials have been undertaken to prove the concept, but further development appears to have stalled (Kamilaris et. al. 2021) or been abandoned (Nason, 2022).

Tucker (2022) summarises the characteristics of blockchain that are disadvantageous to its uptake as follows:

- Each node in the network, by definition, contains a complete copy of the ledger which must be updated when a new block is created. The capability of the chain is therefore limited to the capacity of any single node as the ledger continues to grow (from McKinsey, 2019).
- While the security of blockchain is not in doubt, applications that feed data to and use data from the blockchain are as vulnerable to error, malfunction, or hacking as any other software (Blaha and Katafono, 2020).
- The immutability of records on a blockchain can become a significant weakness in the case of inaccurate data, as error-ridden records are permanently written to the ledger and are therefore impossible to alter. Solutions to this such as automatic data collection and recording may be expensive and difficult to implement.

Furthermore, there are considerable limitations to the bandwidth and reliability of rural internet connections in New Zealand. Any traceability systems requiring on-farm data entry needs to take this into account, and either allow for offline functionality (i.e. batch upload capability) or new technology such as satellite internet connections (for example, StarLink[15]).

[12] OSPRI website: https://www.ospri.co.nz/our-programmes/the-tbfree-programme/history/
[13] Animal Health Board – the organisation responsible for managing Bovine TB in New Zealand from 1993-2013
[14] Dr Alix Barclay, Response Intelligence Manager 2018-2019, MPI
[15] https://www.starlink.com/

5.3 Processor to consumer traceability

Tracing cartons of food, or indeed any commodity, benefits the producer, the consumer, and all parties in between. Accurate records of shipping, inventory, and distribution are crucial for the smooth running of any supply chain (Ramonyai, 2020). It provides assurance to the consumer that the product is true to label and allows the producer to access the market and potentially set a premium price for completely traceable goods.

Perhaps the greatest opportunity for blockchain in the food traceability space is in the battle against food fraud. It has been suggested that in China up to 50% of all beef marketed as Australian is not from Australia, and in many cases is not even beef (Adams, 2019). Food fraud at its worst can cause significant harm, as seen in China in 2008 where melamine was added to infant formula resulting in 54 000 hospitalisations and six deaths. It is therefore understandable that consumers in some markets have become suspicious of food safety and provenance claims (H. Good, personal communication, 23 Feb 2022). Simply maintaining market access may eventually require a verifiable digital chain of evidence, to replace the ageing paper-based certification systems currently in use (C. Burke, personal communication, 31 May 2022[16]).

5.4 Pasture to Plate traceability

The concept of tracing an animal from birth, through processing and distribution to the point of ultimate consumption as a mouthful of food is not new. It ultimately provides for the ability of the consumer to access the life story of the animal they are consuming, to be assured that it was sustainably and humanely raised and is safe to eat. For example, the Netflix television documentary series Hanwoo Rhapsody demonstrates how shoppers in South Korea can use their smartphone to scan the label on a cut of premium Hanwoo beef, resulting in specifications of the animal's origin and husbandry being displayed on the phone's screen (Baek, 2021).

The same level of consumer engagement appears to be lacking when it comes to New Zealand red meat. In 2021, Ovation conducted a trial using QR codes on lamb leg-roasts supplied to Canadian retail stores. The codes linked the user to a web page describing the lamb's farm of origin, including photographs of the farmer and their family. However, of 140 recorded instances of the QR codes being scanned, 139 were found to be internal systems checks. The conclusion was that while the concept was a reasonable marketing gimmick, consumers were not interested in farm-level detail (A. Goodwin, personal communication, 31 May 2022[17]). Hugh Good of Beef + Lamb New Zealand agrees, suggesting that for most consumers "made in New Zealand is good enough" (H. Good, personal communication, 23 Feb 2022).

5.5 Summary of blockchain's applicability to red meat

The most valuable applications for blockchain traceability in a red meat context appear to be biosecurity and proof-of-claim, where the claim may be a farm-level declaration such as "organic" or a country-level declaration such as "made in New Zealand". However, to capture the full value of these applications, solutions to data quality issues must first be addressed.

[16] Dr Colman Burke, Specialist Advisor for Market Access, Ministry for Primary Industries
[17] Adam Goodwin, Ovation Ltd.

6. BARRIERS TO BLOCKCHAIN ADOPTION

In addition to the limitations of blockchain previously mentioned, there are some more general barriers to its widespread adoption:

1. Current technology is fit for purpose
2. Lack of technological maturity
3. Lack of available technological expertise
4. Cost of implementation
5. Widespread disruption to the sector

6.1 Current technology is considered fit for purpose

The most significant barrier to the adoption of blockchain as a traceability solution for the red meat industry is that current requirements are already being met by current technology. McKinsey (2019) notes that for most industries, including agriculture, existing technologies already achieve the desired traceability outcomes.

The adage "if it ain't broke, don't fix it" is deeply ingrained in the farming industry's psyche. For example, the introduction of RFID ear tags for cattle and deer in 2011 was met with a mixed response from farmers at large, with negative sentiment centred on the belief that the AHB barcoded ear tags were performing adequately, so the added expense of RFID tags was unnecessary.

Interviewed meat industry representatives expressed similar concerns about the adoption of blockchain. The NAIT scheme is considered to be fit for purpose and comparable to any other animal traceability scheme worldwide (Edge and Kavalali, 2018) and meat company inventory and product traceability procedures are regularly audited by MPI to international standards[18].

Simply put, the New Zealand red meat industry generally believes that current traceability systems are fit for purpose in today's marketplace (P. Turton, personal communication, 24 May, 2022[19]; J. Gabites, personal communication, 30 May, 2022[20]).

6.2 Lack of technological maturity

The literature is somewhat divided on the topic of maturity when it comes to blockchain, however most peer-reviewed and professionally highly regarded publications consider that blockchain is not ready for large scale use in global trade. This is especially true when it is compared to existing, often purpose-built, technology (McKinsey, 2019). While there have been numerous projects aimed at red meat traceability using blockchain (see Appendix 1), few appear to have progressed past the proof-of-concept stage (Kamilaris et. al., 2021). Nick Rowe of Silver Fern Farms is similarly equivocal on the subject, suggesting that once blockchain is established as a proven technology with a demonstrated

[18] The author has first-hand knowledge as a former MPI Verification Services Animal Products Officer and Veterinary Technical Supervisor
[19] Pat Turton, Business Development Manager, AsureQuality Ltd.
[20] Joel Gabites, Head of Business Improvement, ANZCO Ltd.

ability to integrate seamlessly with existing and new data collection methods, then it may be an appropriate data handling solution (N. Rowe, personal communication, 31 May, 2022[21]).

6.3 Lack of technological expertise

When adopting a new technology, businesses require assurance that appropriate training and technical support are available. Centralised databases have been the norm in business for decades, in which time personnel have become familiar with their use, and highly skilled support services have become readily available. Blockchain is relatively new and poorly understood, and there are few established providers of technical expertise in the blockchain space (Tucker, 2022). Lack of support services and expertise have been identified as a significant barrier to the uptake of new technologies in a New Zealand farming context (Foley, 2022).

6.4 Cost of implementation

The cost to business of implementing blockchain technology from scratch has been assessed as being very high (OPSS, 2020). Furthermore, due to the technology's relative immaturity, it is difficult to calculate the cost ahead of undertaking a transition project. When faced with the level of risk associated with immature technology and unclear costs, rational businesses tend to opt for solutions based upon existing technology (Demir et. al., 2019).

None of the meat industry representatives interviewed had undertaken a detailed cost-benefit analysis on the implementation of blockchain to their businesses.

6.5 Disruption to the sector

The adoption of blockchain across red meat supply chains would represent a paradigm shift for the industry. By definition, a blockchain provides all participants in the supply chain visibility of product flows and assurance of data accuracy. This only works, however, when all participants are represented on the blockchain. If a finishing farmer chose not to participate in the blockchain, proving the identity and provenance of an animal from birth to the time of slaughter would rely on traditional traceability techniques such as paper-based Animal Status Declarations (ASDs). This would be unacceptable in a market that has adopted blockchain as its means of traceability.

To capture the true value of blockchain traceability would therefore require buy-in from across the supply chain – including farms, transporters, saleyards, slaughter and processing plants, exporters, and potentially importers and distributors. Given that these businesses are likely to have their own established and highly functional traceability solutions in place, changing to a new, decentralised system would significantly disrupt existing supply chain architecture. Research suggests that this is generally unpalatable (OPSS, 2020).

A posited solution is to have each step in the supply chain operating its own blockchain that is interoperable with others in the system (Flood and McCullagh, 2020). This, however, introduces a new level of complexity to the supply chain that blockchain was arguably designed to address, further backing up the position that existing technology is fit for purpose.

[21] Nick Rowe, Innovation Manager, Silver Fern Farms Ltd.

7. DRIVERS OF BLOCKCHAIN ADOPTION

Despite the reasons for maintaining the status quo regarding supply chain traceability, there are significant local and global pressures driving industry toward the adoption of new technologies, and increasing capital is invested globally into the research and development of blockchain technologies every year (Statista, 2022). Analysis of the literature has identified three high-level drivers for the adoption of novel technologies such as blockchain into supply chains:

1. Government regulation
2. Customer demand
3. Industry uptake

7.1 Government regulation

The implementation of new technology by private business through government regulation is a possibility. The NAIT scheme, for example, is regulated by its own act, the National Animal Identification and Tracing Act 2012, which places a legal requirement on livestock owners to appropriately tag animals and record their identities on a national database. It is therefore not inconceivable that at some future point, farmers and other red meat supply chain participants may be legally required to upload information to a blockchain.

The potential for such a mandate can be seen in other countries. Hancock (2019) discusses the potential benefits of blockchain traceability to the Kenyan beef industry and points out that its adoption in a country with almost no existing traceability system it would be seen as neither unnecessary nor redundant.

In New Zealand we are currently seeing the development of government-proposed Integrated Farm Planning (IFP), which seeks to improve (among other things) “information sharing across the primary industries” and to “ease regulatory compliance” (MPI, 2022). While the regulatory framework for IFP remains to be finalised and any discussions regarding information management have yet to take place, these objectives are two commonly proposed use cases for blockchain.

7.2 Customer demand

Customer demand can drive technological change. A current example is the massive global uptake of electric vehicles. International agreements such as the 2015 Paris Agreement have led to several governments adopting policies promoting alternatives to fossil fuels as a source of energy. In New Zealand we have seen the introduction of legislation that incentivises consumers to purchase electric rather than petrol- or diesel-powered vehicles. As a result of this global pressure carmakers are directing significant investment into the technology (Lienert and Bellon, 2021).

As previously discussed, there is a global issue with food fraud. Current paper-based traceability systems are targets for counterfeiters, and centralised databases are at risk of hacking. Blockchain has been promoted as a solution to ensure the authenticity of traded products (Dalton et. al., 2018; Kirkness, 2019; Cohn, 2020). A significant portion of the global diamond trade, for example, is now recorded on blockchains, including those traded by industry giant DeBeers (Escobar, 2022).

It does not take a large stretch of the imagination to consider a large market, beset by food fraud, to demand increasingly accurate and verifiable evidence of authenticity from its suppliers. Both China[22] and the European Union[23] have been rocked by food fraud scandals in recent history, which have led to negative cultural, religious, and public health outcomes including severe injury and death. Overall, such scandals can lead to an erosion of public trust in the food supply chain (Smith et. al., 2021). The advantages of blockchain for providing peace of mind to consumers could see it as a regionally or globally adopted standard in the future (Kamath, 2020). The recording of red meat traceability on a recognised blockchain platform could therefore quite easily become a market access requirement, necessitating its adoption across the supply chain.

7.3 Industry uptake

The benefits of blockchain to the traceability of animals and animal products have yet to be widely recognised by the industry. However, the current rapid adoption of sensing and recording systems may lead to a convergence of technologies that finds utility in blockchain as a data storage medium. Pranto et. al. (2021) found that synergies exist between blockchain and the Internet of Things (IoT – see section 8.1) in an agricultural context. The ability to scan, measure, record, sort, categorise, and process information automatically, i.e. without human intervention, is a significant advantage in terms of time savings and the quality of data produced. When added to a secure and immutable ledger on a blockchain this provides a powerful base of evidence upon which to make decisions and base claims.

Such a convergence of technologies on New Zealand farms is not without precedent. As early as 2013 the author found early adopters among farmers who had paired RFID ear tag technology with automatic weighing and draughting systems. This allowed the farmer to automatically weigh cattle, draught them into mobs according to weight class, and record all the information onto their phone via Bluetooth connectivity. Once the farmer was within range of the farmhouse WiFi signal the data file could be automatically sent to their farm advisor or stock agent. This completely removed the potential for human error during data collection.

Sengupta and Kim (2021) suggest that collaboration across the supply chain could result in a critical mass of blockchain adoption. For example, the farmer on the above example might work with their meat company and a software provider to improve or streamline the process, leading to further adoption among other farmers and meat companies. Critical mass would be achieved when the technology is regarded as an industry standard (Hancock, 2019).

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[22] Addition of melamine to infant formula resulting in a public health emergency in 2008

[23] The 2013 discovery of horse, donkey, and pig meat in food products labeled as beef in multiple supermarkets

8. CONVERGENT TECHNOLOGIES

8.1 Internet of Things

It has been previously mentioned that the value of blockchain traceability is only as good as the information loaded onto it, and that this is a major problem within existing traceability frameworks such as NAIT. The solution to recording high-quality data with minimal to no error lies with automated data collection. This is where integration with the Internet of Things becomes valuable (Pranto, et. al., 2021; Picheira et. al., 2022) and could lead to a critical mass of adoption across the supply chain.

Internet of Things (IoT) is a descriptive term for a network of physical objects such as machines, buildings, and devices with integrated sensors, software, and/or processing ability that connect and exchange data. The farmers mentioned in section 7.3 who linked RFID tag readers to weighing scales, automatic draughting systems, and recording software are an early example of IoT functionality. A common example in the consumer market is the concept of the "smart home", where appliances, thermostats, and security systems can be monitored and controlled using a single device such as a smartphone.

IoT technologies are now relatively commonplace in manufacturing and distribution. A customer can, for example, use the internet to order a custom-printed t-shirt from the other side of the world: the design and printing specifications are uploaded automatically into a printing machine, the garment printed, packaged, and shipped, and every step of the process automatically logged with progress reports emailed to the customer. During this process sensors such as cameras and barcode readers share information over the internet, culminating in a final barcode scan by the courier who delivers the package to the customer's door.

The opportunity to integrate IoT technology exists across the entire supply chain and is a topic far larger than would be appropriate to fully investigate for the purpose of this report. The chief drawback of adopting IoT technology is the cost to implement – for example, an "introductory kit" from CeresTag[24] carries an RRP of US$2999. Some IoT applications are summarised below, all of which are either commercially available or undergoing trials:

8.1.1 On-farm tools

- QR-code enabled devices can help record animal treatment information such as product name and batch number, and add stock class description, date, time, and method of application. Software can then calculate a "safe date" for slaughter and automatically link this to an online calendar.
- RFID scanners can record animal ear tags and therefore locate animals to a precise location. Static RFID reader panels can therefore record cattle as they are loaded onto or off a truck, allowing an accurate head count and proof of cartage. Paired with smart contracts this could allow for immediate transfer of animal records and payments between owners.
- Digital photographic and hyperspectral-imaging devices can be used to monitor crop and animal health (Lowe et. al., 2017; Kumar et. al., 2016). Information gathered from, say, a drone-mounted device can be used to record health metrics and enhance on-farm decision-making.

[24] https://www.cerestag.com/

8.1.2 Animal-wearable sensors

- RFID or other Near Field Communication (NFC) devices worn by dairy cows (e.g., on neck or leg collars) can provide accurate records of milk production and allow specified dietary provision for each animal.
- Animal location can be monitored by ear tags enabled with Bluetooth (Bloch and Pastell, 2020) or GPS (CeresTag).
- Implantable and ingestible sensors can and measure several physiological metrics including temperature, heart rate, respiration rate, blood oxygen, simple blood plasma and sweat chemistry, ketones, antibiotics, toxins, and even movement and behavioural characteristics (Nagl et. al. 2003; Neethirajan, 2017).
- Gas analysers can detect Volatile Organic Compounds (VOCs) on the breath of an animal, and analysis can provide an indication of the animal's health status. Such a device mounted on a water trough and paired with an RFID tag reader can provide a snapshot of an animal's health every time it takes a drink.

8.1.3 Slaughter plant sensors

- Research is currently underway on the application of spectroscopic and visible-light imaging systems capable of detecting disease in offal (e.g., liver or lungs) at meat plants in New Zealand. Collected data can be communicated to staff at the meat plant and to the farmer (Dixit, 2022 (unpublished)).
- Invasive and non-invasive techniques have been developed to measure intramuscular fat and predict meat quality in slaughter plants, which can be used to grade product and provide feedback to the farmer (Dixit and Al-Sarayreh, 2020; Dixit and Hitchman, 2020).

8.2 Machine learning and Artificial Intelligence

Machine learning involves the development of algorithms that create a model based on sample data to make predictions or decisions. It is a part of Artificial Intelligence (AI), which refers to a system that seeks to identify and solve problems through such concepts as reasoning, planning, learning, and rationality (Hu et.al. 2020).

Machine learning is already being applied to some of the technologies mentioned in section 8.1. The 2022 NZ Meat Innovation Workshop[25] included six presentations that directly or indirectly referred to the use of machine learning and AI at various points in the supply chain. For example, machine learning is improving the accuracy of the diagnosis of certain conditions from spectroscopic imaging of lamb livers post-mortem.

Soon AI may be able to parse all manner of information from meat prices to weather forecasts, consider these in combination with pasture growth and animal liveweight gain, and provide the farmer with optimised solutions for livestock grazing and trading strategies.

A vision of the future, including some of the technologies mentioned here, is provided in appendix 2.

[25] Palmerston North, 31 May-1 June 2022

9. CONCLUSIONS

Blockchain technology has the proven ability to streamline the sharing of information securely and provide end-to-end traceability of products through a supply chain. Some industries have embraced the technology, but blockchain's integration into red meat supply chains globally has so far failed to get past proof-of-concept or trial stages. The reasons for this are multifactorial, but can be summarised as follows:

- Current technology is considered fit for purpose
- There is doubt surrounding the maturity of the technology
- There are not enough services in place to support widespread blockchain adoption
- The cost of implementation is difficult to predict and likely to be high
- Mass adoption across the supply chain would be required for it to work
- Rural internet infrastructure will require significant improvement to ensure functionality

There are several potential benefits, however, associated with the uptake of blockchain by the red meat sector:

- Enhanced animal and animal product traceability
- Digital proof of provenance to combat food fraud
- The ability to utilise smart contracts to streamline peer-to-peer transactions
- The potential to leverage technological convergence in the form of IoT and machine learning to achieve greater efficiencies

Additionally, the uptake of new technologies can (and has) become compulsory due to government regulation and market demand.

Perhaps the biggest opportunity for blockchain lies with its convergence with other technologies such as the Internet of Things and Artificial Intelligence. The combination of integrated and remote sensing technology with near-field communications, machine learning, blockchain, and smart contracts has the potential to allow high-quality data collection and distribution, improved decision-making, and streamlined financial transactions, while providing immutable proof of origin and safety.

While existing systems are able to fulfil the demands currently placed upon them, changing demands may require a change in systems. For the New Zealand red meat sector to avoid having the terms of such a change dictated to it by its own or a foreign government it is crucial to be forearmed with knowledge and expertise. Industry-led adoption of technological change should ensure that systems are fit for purpose with appropriate user interfaces.

Being blockchain-ready will help the New Zealand red meat industry maintain its reputation as a world leader, and leave it better prepared to meet the future demands of global red meat trade.

10. RECOMMENDATIONS

The New Zealand red meat industry cannot afford to dismiss blockchain technology as unnecessary or unfit for purpose. There is a very real possibility that technological change may be forced upon the industry by government regulation or customer demand. To fully capitalise on the benefits that blockchain can provide, the sector should take the lead on the development of the technology. This will ensure that usability and functionality are relevant and appropriate to all stakeholders.

Therefore, the following recommendations are made:

- The red meat sector should focus on adoption and development of new technologies including sensing and machine learning, with a mindset geared toward technological interoperability. Even if blockchain is not mandated as an industry standard there will be efficiency and productivity benefits.

- RFID ear tag scanners should be mandated on livestock trucks. Transport providers are the choke point for animal traceability from source to destination, making them the logical place for ID scanners to be installed. Scanning animals on and off the truck after every movement will provide highly accurate data to feed into a traceability blockchain.

- The primary sector should continue to lobby for improved internet connectivity in rural areas, to enable the full potential of new and emerging digital technologies to be realised.

- Sector research providers including universities and crown research institutes such as AgResearch and Plant and Food Research should collaborate with IT providers, blockchain specialists, and industry to identify and develop blockchain solutions for animal and red meat traceability that benefit the national supply chain.

- International trends and legislation should be closely monitored, and agreements reached between governments to ensure an adequate lead-in time when blockchain traceability becomes an import requirement.

By taking the lead in blockchain development, the industry can ensure it has future-proofed itself with a functional and fit-for-purpose traceability system linked to farm and processor management systems. The red meat sector will therefore be adequately prepared for blockchain to be adopted as the new global standard for food traceability.

REFERENCES

Adams, P. (2019). *China is hungry for Australian beef, but every second kilo shoppers buy could be fake*. ABC news, 3 November 2019. Retrieved on 11 March 2022 from https://www.abc.net.au/news/2019-11-03/blockchain-detecting-beef-fraud-in-australian-exports-to-china/11662950.

Baek, Jong-won (writer/director/producer). (2021). Season 1, episode 1, *Hanwoo Rhapsody*. Netflix.

Banerjee, A. (2022). *Everything you need to know about consortium blockchain.* Blockchain Council. Retrieved on 11 March 2022 from https://www.blockchain-council.org/blockchain/everything-you-need-to-know-about-consortium-blockchain/#:~:text=Consortium%20blockchain%20offers%20the%20new,also%20known%20as%20Federated%20blockchains.

Blaha, F., and Katafono, K. (2020). *Blockchain application in seafood value chains.* FAO, Rome.

Bloch, v., and Pastell, M. (2020). *Monitoring of cow location in a barn by an open-source, low-cost, low-energy bluetooth tag system.* Sensors 2020, 20, 3841.

Bulla Network. (2022). *Blockchain and AI tech collab improves supply chain and enables world's first cattle NFT sale.* Retrieved on 15 March 2022 from https://www.linkedin.com/pulse/blockchain-ai-tech-collab-improves-supply-chain-enables-/?trackingId=qooGMtzXTwyhu1WG9p5H8w%3D%3D

Burger, S. (2021). *Blockchain-based e-livestock supply chain traceability system launched in Zimbabwe.* Engineering News. Creamer Media. Retrieved on 11 March 2022 from https://www.engineeringnews.co.za/article/blockchain-based-e-livestock-supply-chain-traceability-system-launched-in-zimbabwe-2021-06-18/rep_id:4136

Casey, M. J. and Wong, P. (2017). *Global supply chains are about to get better, thanks to blockchain*. Harvard Business Review. Retrieved on 11 March 2022 from https://hbr.org/2017/03/global-supply-chains-are-about-to-get-better-thanks-to-blockchain

Cohn, A. (2020). *Blockchain at our borders.* In Tapscott, D. (Ed), *Supply Chain Revolution; how technology is transforming the global flow of assets* (pp 53-63). Barlow Books, Toronto.

Dalton, D., Day, A., Leonowicz, C., Connaughton, A., and McManus, J. (2018). *Beefing up Blockchain: how blockchain can transform the Irish beef supply chain*. Deloitte, Belfast.

Demir, M., Turetken, O., and Ferworn, A. (2019). *A Financial Evaluation Framework for Blockchain Implementations.* Proceedings of the 10th Annual Information Technology, Electronics and Mobile Communication Conference, Vancouver, 17-19 October 2019.

Dixit, Y., Al-Sarayreh, M., Craigie, C., and Reis, M. (2020). *A global calibration model for prediction of intramuscular fat and pH in red meat using hyperspectral imaging*. Meat Science. 181. 108405. 10.1016/j.meatsci.2020.108405.

Dixit, Y., Hitchman, S., Hicks, T., Lim, P., Wong, C., Holibar, L., Gordon, K., Loeffen, M., Farouk, M., Craigie, C., and Reis, M. (2020). *Non-invasive spectroscopic and imaging systems for prediction of beef quality in a meat processing pilot plant*. Meat Science. 181. 10.1016/j.meatsci.2020.108410.

Edge, M. and Kavalali, B. (2018). *NAIT review: final report on the recommendations.* OSPRI.

Escobar, S. (2022). *How This Company Is Using Blockchain to Buff Up the Image of Diamonds.* Barron's. Retrieved on 15 March 2022 from https://www.barrons.com/articles/brilliant-earth-blockchain-diamonds-51647294829?tesla=y

Flood, J. and McCullagh, A. (2020). *Blockchain's future: can the decentralized blockchain community succeed in creating standards?* The Knowledge Engineering Review. Cambridge University Press.

Foley, F. (2022). *What are the barriers to the adoption of new technologies and innovation by the New Zealand farmer?* Kellogg Rural Leadership Programme, Course 45.

Hancock, C. N. (2019). *The integration of blockchain to the beef industry – a comparative analysis.* Social Impact Research Experience (SIRE). 71. Wharton Undergraduate Research, University of Pennsylvania.

Hu, J., Niu, H., Carrasco, J., Lennox, B., and Arvin, F. (2020). *Voronoi-Based Multi-Robot Autonomous Exploration in Unknown Environments via Deep Reinforcement Learning.* IEEE Transactions on Vehicular Technology, vol 69, no. 12, pp 14413-14423.

Jenkinson, G. (2018). *Crypto and Blockchain — Following in the Footsteps of Man's Greatest Inventions?* Retrieved on 9 April 2022 from https://cointelegraph.com/news/crypto-and-blockchain-following-in-the-footsteps-of-man-s-greatest-inventions

Kamath, R. (2020). Food traceability on blockchain. In Tapscott, D. (Ed), *Supply Chain Revolution; how technology is transforming the global flow of assets* (pp 53-63). Barlow Books, Toronto.

Kamilaris, A., Cole, I., and Prenafeta-Boldu, F. X. (2021). Blockchain in agriculture. In Galanakis, C. (Ed) *Food Technology Disruptions* (pp 247-276). Elsevier.

Kirkness, J. (2019). *Traceability technology for food manufacturers: how to be ready for blockchain.* Version 1. Judith Kirkness, Canada. Independently published.

Kumar, A., Saxena, S., Shrivastava, S., Bharti, V., Kumar, U., and Dhama, K. (2016). *Hyperspectral Imaging (HSI): Applications in Animal and Dairy Sector*. Journal of Experimental Biology and Agricultural Sciences. 4(4): pp 448-461.

Lienert, P. and Bellon, T. (2021). *Exclusive: Global carmakers now target $515 billion for EVs, batteries.* Reuters. Retrieved on 9 April 2022 from https://www.reuters.com/business/autos-transportation/exclusive-global-carmakers-now-target-515-billion-evs-batteries-2021-11-10/

Lowe, A., Harrison, N. & French, A.P. (2017). *Hyperspectral image analysis techniques for the detection and classification of the early onset of plant disease and stress.* Plant Methods 13, 80.

MPI. (2022). Integrated Farm Planning Work Programme. Retrieved on 15 March 2022 from https://www.mpi.govt.nz/funding-rural-support/farming-funds-and-programmes/integrated-farm-planning-work-programme/

McKinsey. (2019). *Blockchain's Occam problem*. McKinsey. Retrieved on 15 March 2022 from

https://www.mckinsey.com/industries/financial-services/our-insights/blockchains-occamproblem

Marvin, R. (2017). *Blockchain: the invisible technology that's changing the world.* PC Magazine Australia. Retrieved on 11 March 2022 from https://au.pcmag.com/enterprise/46389/blockchain-the-invisible-technology-thats-changing-the-world

Mehta, N., Agashe, A., and Detroja, P. (2021). *Bubble or Revolution? The present and future of blockchain and cryptocurrencies*. 2nd Edition. Paravane Ventures.

Nagl, L., Schmitz, R., Warren, S., Hildreth, T., Erickson, H., and Andresen, D. (2003). *Wearable Sensor System for Wireless State-of-Health Determination in Cattle*. Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings. 4. 3012 - 3015 Vol.4.

Nash, K. S. (2016). *IBM pushes blockchain into the supply chain.* The Wall Street Journal. Retrieved on 20 May 2022 from https://www.wsj.com/articles/ibm-pushes-blockchain-into-the-supply-chain-1468528824

Neethirajan, S. (2017). *Recent advances in wearable sensors for animal health management.* Sensing and Biosensing Research 12 (2017) pp 15-29.

New Zealand Farm Assurance Programme (NZFAP) Standard (2021). Version 4, September 2021. New Zealand Farm Assurance Inc.

Northern AG Network. (2019). *First-Ever Blockchain Beef Shipment Traced from Wyoming to Taiwan.* Retrieved on 15 March 2022 from www.northernag.net/first-ever-blockchain-beef-shipment-traced-from-wyoming-to-taiwan/.

Nason, J. (2022). *Liquidator appointed to blockchain provider BeefLedger*. Beef Central. Retrieved on 11 March 2022 from https://www.beefcentral.com/news/liquidator-appointed-to-beef-blockchain-provider-beefledger/

OPSS. (2020). *The use of distributed ledgers to verify the provenance of goods*. Office for Product and Safety Standards, Department for Business, Energy, and Industrial Strategy.
Retrieved on 11 March, 2022 from
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/923608/use-distributed-ledgers-verify-provenance-goods.pdf

Pincheira, M., Vecchio, M., and Giaffreda, R. (2022). *Characterization and Costs of Integrating Blockchain and IoT for Agri-Food Traceability Systems.* Systems 2022, 10, 57.

Pranto, T.H., Noman, A.A., Mahmud, A., and Haque, A.B. (2021). *Blockchain and smart contract for IoT enabled smart agriculture.* PeerJ Computer Science 7:e407. https://doi.org/10.7717/peerj-cs.407

Proudfoot, I. and Keeys, J. (2021). *KPMG Agribusiness Agenda 2021 – New Zealand, our consumers, and our 2040 future*. KPMG.

Pyliandis, C., Osinga, S., and Athanasiadis, I. N. (2021). *Introducing digital twins to agriculture.* Computers and Electronics in agriculture. Vol 184, pp 1-25.

Ramonyai, J. (2020). *Supply chain management.* Jerry Ramonyai. Independently published.

Sengupta, U., & Kim, H. M. (2021). *Meeting Changing Customer Requirements in Food and Agriculture Through the Application of Blockchain Technology.* Frontiers in Blockchain, Volume 4.

Smith, M., Ashraf, M., Austin, C., and Lester, R. (2021). *Product fraud: Impacts on Australian agriculture, fisheries, and forestry industries*. AgriFutures Australia.

Statista. (2022). *Worldwide spending on blockchain solutions from 2017 to 2024.* Retrieved on 24 May 2022 from https://www.statista.com/statistics/800426/worldwide-blockchain-solutions-spending/

Taunton, E. (2019). *NAIT: a difficult beast but NZ had "no chance" against M. bovis without it.* Stuff, 25 March, 2019. Retrieved on 9 April, 2022 from https://www.stuff.co.nz/business/farming/111532371/nait-a-difficult-beast-but-nz-had-no-chance-against-m-bovis-without-it

TE-FOOD. (2022). *Dong Nai province in Vietnam starts to roll out TE-FOOD's traceability system from May*. Retrieved 9 April, 2022 from https://medium.com/te-food/dong-nai-province-in-vietnam-starts-to-roll-out-te-foods-traceability-system-from-may-b8bc009d604a

Tucker, J. (2022). *How can technology add value for farmers and regulators in a livestock traceability scheme?* A research report submitted in partial fulfilment of the requirements for a Master's degree in Business Administration, Massey University.

Williams, A. D. (2020). Diamonds on the blockchain. In Tapscott, D. (Ed), *Supply Chain Revolution; how technology is transforming the global flow of assets* (pp 53-63). Barlow Books, Toronto.

Wolf, M. (2022). *'It's like a driver's license for cows': why one Wyoming company is creating NFTs for cattle.* The Spoon. Retrieved on 20 May 2022 from https://thespoon.tech/its-like-a-drivers-license-for-cows-why-one-wyoming-company-is-creating-nfts-for-cattle/

APPENDIX 1 – Short list of known projects using blockchain for red meat traceability

- TE-FOOD describes itself as "The #1 end-to-end food traceability solution on blockchain" and claims to service over 6000 business customers worldwide (https://te-food.com/). It has recently embarked on a large traceability project for pork in Vietnam[26].

- The Botswana Ministry of Agriculture is developing a blockchain-enabled IoT system for tracking cattle (https://chester-beard.medium.com/cattle-iot-and-blockchain-in-botswana-4b059e64deca).

- Zimbabwe is currently seeing the rollout of the E-Livestock Global traceability system, which sists on the Provenance blockchain developed by Mastercard (https://www.engineeringnews.co.za/article/blockchain-based-e-livestock-supply-chain-traceability-system-launched-in-zimbabwe-2021-06-18/rep_id:4136).

- Wyoming-based BeefChain (https://beefchain.com/) has been certified by the US Department of Agriculture as a Process Verified Programme, becoming the first blockchain company to do so.

- BeefLedger (https://beefledger.io/) is an Australian blockchain company offering end-to-end traceability solutions for beef production. BeefLedger was placed in external administration in March 2022.

- TraceX Technologies (https://tracextech.com/) is a blockchain powered food traceability platform based in India.

- NSF (https://www.nsf.org/testing/food) is a global provider of testing, inspection, and certification services. In 2020 it formed a consortium with Fujitsu UK, the Institute of Global Food Security at Queen's University, B4B Telecoms Ltd and Samsung Electronics to build a blockchain-based agri-food supply chain system called NSF-Verify (https://www.nsf.org/news/new-consortium-uses-blockchain-technology-to-protect-northern-ireland-agriculture-products-in-world-markets).

- Neogen (https://www.neogen.com/), a US-based provider of genetic and diagnostic testing technologies, has partnered with blockchain provider Ripe Technology Inc (https://www.ripe.io/) to automate and enhance food safety (https://www.neogen.com/neocenter/press-releases/neogen-partners-with-ripe-io-to-bring-blockchain-to-food-safety-and-animal-genomics/).

[26] https://medium.com/te-food/dong-nai-province-in-vietnam-starts-to-roll-out-te-foods-traceability-system-from-may-b8bc009d604a

APPENDIX 2 – A vision of the future

It's 8 am and Sam's phone beeps with an alert. An app has identified that the truck coming to pick up a mob of steers for the works is approximately 30 minutes away, giving Sam just enough time to double-check each animal's RFID tag and have a cup of tea. The truck arrives and the steers are loaded – the RFID reader installed in the truck's loading door automatically records each animal as it enters, and an automatic check of the blockchain shows they are all outside any treatment withholding periods. When the door closes a prompt appears on Sam's phone: MARK ANIMALS IN TRANSIT? Sam taps YES and simultaneously three databases are updated: the farm's, the transport company's, and the slaughter plant's. A digital record now shows that the steers are no longer present at the farm and are en route to the slaughter plant. The same RFID reader will record when they disembark from the truck at the end of their journey, and a smart contract will be triggered which will send automatic billing information from the transport company to Sam's phone.

With the steers loaded and gone, Sam needs to head to town for supplies. After consulting with a vet based on the latest faecal egg count results, Sam selects a drum of sheep drench to purchase. The QR code on the drum is scanned and a digital record now shows the drum being transferred from the vet clinic's inventory to the farm's inventory. When it's time to use the drench, Sam scans the code again and follows the prompts to enter the mob being drenched. Data from the weigh-scales is used to calculate the dose rate, and the drench type, batch number, and withholding period are applied to the digital description of the animals. The updates are loaded onto the blockchain, and a smart contract automatically submits a notification to the farm's assurance programme provider that pharmaceutical stewardship protocols are being adhered to.

Another alert pops up as Sam drives home. A water flow sensor has detected that a drinking trough in the bull paddock has been drawing water a twice the normal rate for 20 minutes. There is a drone nearby using its visible- and infrared-spectrum cameras to perform a daily headcount of the lambs on the crop – the AI recommends diverting it to capture images of the trough. Sam clicks AGREE and the drone buzzes over to the bull paddock to discover that the ballcock has popped off. A few taps on the screen shuts off the feed to that section of pipe. Sam sends a quick message asking shepherd Alex to fix the trough, and the drone returns to its job. A quick check reassures Sam that a record has been uploaded to the blockchain showing that the quick response to the leak means the farm remains within the limits of its water use target.

When Sam gets home the AI has prepared a report noting that pasture growth has slowed in a couple of south-facing paddocks and suggesting some changes to the grazing plan. Sam clicks AGREE and opens the post-mortem report that's just been uploaded to the blockchain by the meat company's system. It shows middle grades for intramuscular fat (still beating the regional benchmark for steers) and liver copper measurements trending downward from last month. Sam is prompted to share these finding with the vet and clicks AGREE.

A final alert signals that a smart contract has triggered payment for the steers.

Author's note: all the technologies mentioned above exist. The trick is bringing them together.