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A framework for traceability of hides for improved supply chain coordination

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ABSTRACT

Hides are an important co-product of the meat processing industry which are further used in leather production. However, there is a lack of automated traceability systems in this industry. A traceability system can improve data capture and information exchange between the stakeholders of a hide supply chain which can further improve supply chain coordination. Such a system can be used to provide important feedback to the producers about handling practices on the farm as well as provide relevant product information to the customers. A traceability system for the Norwegian hides supply chain is proposed in this paper. Various data capture technologies including RFID, dot peening and laser engraving were tested in a pilot setting. Pilot tests showed that traceability from the farm to the hide processor is possible using the RFID enabled hide tags up to the tanning process. If the machine-readable requirement is not necessary, laser engraving can be used for traceability covering the entire supply chain including the tanning process. Costs and benefits of proposed technologies are presented. Security concerns related to the use of RFID tags are also discussed.

1. Introduction

Hides are one of the most important co-products produced by the meat industry as they are further processed and used in leather production. Individual identification of animals by means of body markings dates back over 3800 years (Blancou 2001). Traceability is very important to manufacturing companies, not only does this ensure safety to the consumers by guaranteeing the origin of the products, optimizing logistics and management, but also for complying with laws and regulations (Cataldo et al. 2016).

One of the driving forces behind traceability is improved supply chain management. A product that is traceable helps build consumer trust. This is particularly true for countries where consumer confidence in the government's ability to protect the safety of the food supply has been weakened as in the EU and Japan in the wake of BSE (Clemens 2003). Subsequently, for the meat sector human and animal health concern has been identified as one of the key motivations for adopting traceability systems (Hobbs et al. 2005).

Hobbs et al. (2005) stated three separate functions of a livestock and meat traceability system:

(1) ex post cost reduction, which allows for traceback of products or animals through the supply chain in the event of a food safety problem;
(2) to enhance the effectiveness of Tort Liability Law as an incentive for firms to produce safe food; and
(3) to reduce information costs for consumers by facilitating the labelling of credence attributes, including those related to food safety, animal welfare, environmental-friendly product practices, etc.

Additionally, in some instances, traceability systems may be introduced to correct perceived market failures when firms fail to supply the socially optimal level of traceability (Hobbs et al. 2005).

A big concern for the millennial society is preservation of the environment. Consumers want to know the eco-friendliness of the products they buy, and traceability information is required in different sectors other than food (Germani et al. 2015). This is of high relevance for the leather companies. Leather production has high water and chemical consumption and is known to have a negative impact on the environment. Especially processes like tanning, drying, dyeing and finishing that use chemicals are reported to generate high environmental impacts. Consumers are paying attention to the origin of certain brands of products as part of their purchasing decision (Kalicharan, 2014, Bandyopadhyay and Banerjee, 2003, Cordell, 1991). Kalicharan

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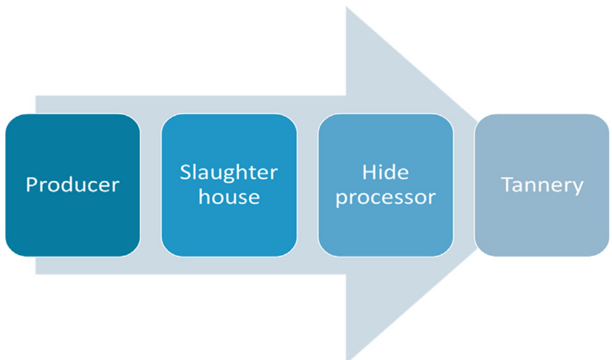

Fig. 1. Typical supply chain of cattle hides.

(2014) found that the country of origin does matter for status and image-oriented products to consumers that have ethnocentric belief systems, and to the growing middle-class consumers in emerging economies.

The main objective of any tracking system is to find the best-fit technology to minimise the effort to capture timely and accurate information as a product moves through a supply chain. There are many well established state-of-the-art solutions for tracking of goods (e.g. antennas and radiofrequency identification (RFID)). However, traceability in the leather manufacturing industry is an unresolved problem. Traditional tracking solutions in many cases do not represent a viable solution for tracking of hides, as they do not survive the stressful tanning process where the hides are subject to both chemical and mechanical stressors.

While several possible technologies for the first and last segments of the supply chain exist, the tanning process is driving the search for viable options as it is considered to be the weakest link (Cataldo et al., 2016). Permanent subsurface tattoos using two types of identification markers: metallic paint and barium titanate were tested by Cataldo et al. (2016) where two different sensing technologies: X-ray scanning and microwave reflectometry (MR) were used to check the presence of injected markers before and after the tanning process. Only one hide was used for testing and an industrial scale up is recommended for further investigation. Agrawal et al. (2018) provided a systematic overview of various technologies for traceability and also mentioned that sub-surface tattoo could help reduce counterfeits.

The Gibson Bass Stamper developed by Joe Gibson in 2001 is also used for marking hides. It is a computer controlled stamping system which can stamp individual letters, numbers or codes onto a hide or skin at any stage of the tanning process. The stamps seem to last through the tanning process (Gibson, 2016).

These methods however do not provide the full supply chain traceability. They fail to link additional information such as product quality and origin to the individual hide. The need of X-ray and MR scanners also make these systems very costly for industrial implementation.

Several technologies recommended for the meat industry could also be viable for tracking of hides in different parts of the supply chain. For tracking of the pig meat supply chain, Fenu and Garau (2009) proposed a system implementing different RFID technologies. At the farm Low Frequency (LF) RFID ear tags were fitted to all animals when they were few days old or when they entered the farm. When the butchering process began, the ear tag was no longer a viable option. Abraham et al (2014) proposed a similar system, introducing two different ear tags, where one is the visual ear tag and the other an electronic RFID chip. Both tags accompany the animals from farm to slaughter, when the device for the register of live animals is delisted.

RFID tracking has been suggested by many as the most viable option

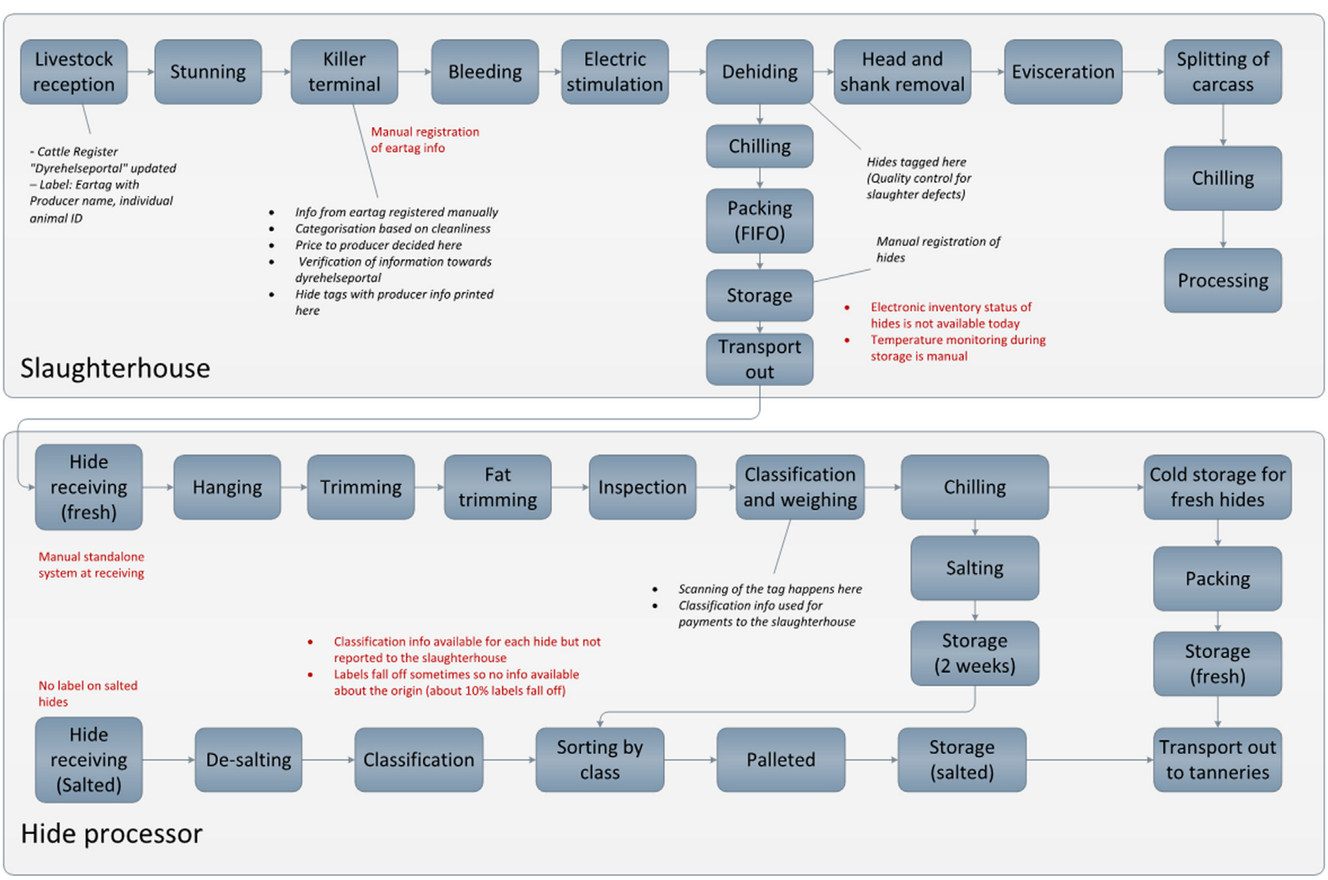

Fig. 2. Process Map of the slaughterhouse and the hide processor.

Table 1
Description of critical processes in the hide chain.

Process	Description	Information received	Information recorded	Use of information
Livestock reception *Unique ID: Ear tag*	Producers inform about the animals ready for slaughter via phone or website. This information goes to the Norwegian Food Safety Authority along with full traceability and health information. When approval is received, the pickup of cattle is arranged by the slaughterhouse.	Producer name and Individual animal ID from the ear tag (this info is already in the system and checked)	– Producer name – Individual animal ID	Cattle register updated
Killer terminal	After stunning, the animals are slaughtered at the killer terminal. Cleanliness inspection is also done here, and the hides are categorized into categories 1 and 2.	– Producer name – Individual animal ID	– Manual registration of ear tag – Hide category	– The farmer gets paid by weight and quality at time of loading not receiving. – Hide tags with producer information are printed
Dehiding	Hides are removed from the animals and quality is checked based on slaughter defects. Hides go directly for chilling and packing.	– Producer name – Individual animal ID	Hides are tagged here	Slaughter defects can be linked to the operator and payments from the hide processor to the slaughterhouse uses the information about slaughter defects
Storage	Hides are stored after chilling and packing. Packing is done in a big box with 8–10 hides per box. Transportation to the hide processor takes place almost every day.	Hide tag	Manual registration of hides	Inventory status is managed manually.
Hide receiving	Hides are received from the slaughterhouse and registered manually in the standalone system.	Hide tag	– Hide ID – Temperature – Number of boxes	Daily record of incoming hides. The process line follows FIFO principle.
Classification and weighing	Hides are weighed, and also classified into 3 classes based on quality.	Hide tag	– Classification – Weight of hide – Slaughter defects	The information is used for payment settlement with the slaughterhouse

for tracking of goods within various supply chains including meat (Yiying et al., 2019, Grande and Vieira 2013, Mousavi et al., 2002).

The next section describes the Norwegian hide supply chain and presents the objectives of this study.

1.1. Hide supply chain

The hide supply chain consists of a producer (farm), slaughterhouse, hide processor and a tannery as shown in Fig. 1. Norwegian cattle hides are world-class and are used in the luxury market to produce handbags, belts, shoes, and upholstery. Hide production in Norway was about 2.1 thousand tonnes in 2015, declining by an average annual rate of 15.3% from 2008 (Index box, UK, 2016). In 2017, a total of 293 371 cattle hides were produced in Norway. Norwegian hides are known for their high quality and farmers earn up to 30 euros per animal when sold to international tanners. This hide is turned into luxury handbags each costing up to 4700 dollars by big brands (Thornews, 2014).

The description of various stakeholders in the hide supply chain is as follows:

- Producer (farmer) – raises the cattle for meat production
- Slaughterhouse – Buys cattle from the producers and slaughters and further processes into various meat products
- Hide processor – Buys the hides from the slaughterhouses and processes them further, and sells to tanneries for leather production
- Tannery – Buys fresh and salted hides from the hide processor and produces leather and leather products
- Customer – Buys leather products

This study focusses on developing a traceability framework that will enable data capture and sharing among the supply chain partners. The main goal is to provide the information about the origin of hides to the tannery as well as provide feedback on the hide quality to the upstream actors such as the producer and slaughterhouse which can be used by them to improve their handling and production practices. The quality of hides is affected due to any surface injuries caused during production and slaughter processes. Presence of lice on the cattle can also affect the quality of hides. Currently this information is not shared by the hide processor with either the producer or the slaughterhouse.

These objectives are achieved by:

(1) mapping the current hides supply chain in Norway
(2) identifying and testing various data capture technologies in a pilot setting
(3) proposing a traceability system for improved traceability and supply chain coordination

The study also examines the costs and expected benefits of implementing the proposed traceability system.

2. Methodology

The hide supply chain was mapped using the process mapping technique focussing on operations at the slaughterhouse and hide processor to determine the current flow of materials and the information recorded at different stages in the process. An AS-IS process map was developed using this information. Stakeholders' requirements were established based on the information gathered during the process mapping and interviews with the slaughterhouse and the hide processor.

Once the process map and stakeholders' requirements were established, various data capture technologies including RFID solutions, dot peening and laser engraving were tested in an industrial pilot setting. The goal was to test the survivability of these solutions through the supply chain from the slaughterhouse to the tannery.

A TO-BE process map including the suggested information flow in

Fig. 3. Ear tag and hide tag.

the hide supply chain for improved traceability and supply chain coordination was proposed.

3. Results

3.1. AS-IS process map

The AS-IS process map is represented in Fig. 2. The process maps indicate the current flow of materials and information recorded at different stages in the process. The process at the slaughterhouse starts with livestock reception where the information from the ear-tag attached to each animal is recorded including the name of the producer and the individual animal ID. The "Cattle register" is updated with this information. The critical processes where information is recorded are described in Table 1. The hide tag and ear tag currently used as shown in Fig. 3.

The killer terminal and dehiding processes are critical points in the supply chain of hides. The information about quality and slaughter defects is recorded here and can be linked to a specific animal and producer. This information is used for processing payments by the slaughterhouse to the producer. The hide processor carries out its own classification of hides and checks for slaughter defects and any other surface defects. This information is used for settling the payments to the slaughterhouse.

There is a lot of information available in the hide supply chain, but it is not shared with other stakeholders. For example, the information about slaughter defects, although recorded by the hide processor for each hide, it is not shared at the same level of granularity with the slaughterhouse. So, it cannot be used by the slaughterhouse to improve their slaughter process. The surface defects can also be caused at the farm due to lice or any other diseases, but this is not shared with the slaughterhouse or the producer.

During the process mapping, requirements for each stakeholder were identified and these presented in the next section.

3.2. Stakeholder requirement specifications

Interviews were conducted with the slaughterhouse and the hide processor using a semi-structured interview approach to understand the requirements of various stakeholders in the hide supply chain. Based on these interviews, various stakeholder requirements were identified. Requirements of the producer are based on information from the slaughterhouse which is a producer-owned company. Requirements of the tannery and customers are based on the experience of the hide processor that sells hides for further processing to various tanneries. Additionally, customer requirements were verified from published literature.

Recent literature also shows the increasing demand for sustainably produced leather as "vegan" leather industry grows as a competitor (Cline 2019). Several consumer surveys and studies show that customers are concerned about the genuineness of leather products and often relate the manufacturing country with quality of the product (Carrier, 2014, Kalicharan 2014). In an assessment based on consumer survey and secondary sources for leather labelling at EU level, consumers expressed preferences for products with a particular country of origin and limited environmental impact, as well as expressed their willingness to pay higher prices for these products (European Commission, 2013). The results from another survey show that, in the 16–34 age group, ecological impact, ethics, and the country of origin of goods are important determinants in the consumer's decision process when he or she buys apparel. A research paper investigating the awareness of Romanian consumers towards ethical leather footwear highlights that consumers are interested in ethical footwear, but the knowledge and information they have are limited (Luca et al., 2016).

The main requirements for each stakeholder can be described as following:

- Producer – receive information about surface defects e.g. lice and other handling defects
- Slaughterhouse – receive information from the hide processor about surface defects caused during slaughter
- Hide processor – receive information about animal origin, slaughter information, chain of custody, number of hides available for processing
- Tannery – receive information about animal origin, additional attributes like ecological hides and/or environmental considerations, chain of custody
- Customer – receive information about animal origin, additional attributes like ecological leather and/or environmental considerations

3.3. Pilot tests

Several data capture technologies for traceability of hides through the supply chain were tested in an industrial pilot setting. A general overview of the five different technologies tested are shown in Table 2. The technologies tested included three different RFID solutions, dot peening and laser engraving.

RFID solutions included Low Frequency (LF) RFID tags similar to those used for microchipping of pets, coupled ultra-high-frequency (UHF) RFID tags, and RFID tags that were glued onto the traditional hide labels used at the hide processor.

The LF RFID tags, UHF RFID tags, dot peening and RFID enabled hide tags were tested on fresh hides while the laser engraving were tested on both fresh and salted hides. Preliminary tests were conducted on fresh hides using the LF RFID tags, UHF RFID tags, dot peening and laser engraving with 2, 10, 4 and 2 fresh hides respectively. Preliminary tests were conducted to check the feasibility of these technologies and whether they could withstand the tanning process. Hides tagged using

Table 2
Summary of the results from different technologies tested in the pilot setting.

Tagging technology	Equipment used	Raw material tested	Benefits	Challenges	Readability
Ultra-high Frequency (UHF) RFID	RFID tags from Smartrac and Trap NF, Nordic ID Stix reader	Fresh hides (n = 2)	● State of the art technology ● Individual tagging ● Batch reading ● Cheap tags	● The process needs automation ● Does not operate well in or close to aqueous fluids ● Large size	Tags were lost or unreadable after the tannery.Readability: 0%
Low Frequency (LF) RFID	Tags from Dyreidentitet AS, used for microchipping of pets.	Fresh hides (n = 10)	● Made for hide tagging ● Adhesive that bonds to organic materials.	● Very close-range readability ● Difficult to inject the tag	Tags could not be found after the tannery. Readability: 0%
Dot Peening	SIC Marking E1 123 Marking system	Fresh hides (tested both QR-code and text) (n = 4)	● Readable after the tannery ● Portable device with fixed mount ● Simple technology ● Low operating cost ● Wide marking window ● Robust and lightweight (2 kg)	● Not possible to read markings on hides with hair ● Mainly used for marking metal ● The needle was rough on the material ● Need to shave the area used for marking	Could not read the markings because the hides were not shavedReadability: 0%
Laser engraving	30 W MACSA laser and Godex GD550 2D barcode reader	Fresh and salted hides (tested both QR-code and text) (n = 2)	● Handheld equipment	● Hard to read markings on hides with hair ● Hard to scan the markings ● The process needs automation ● Availability of equipment	Text was readable after tanning. The QR code was unreadable. Readability: 0% for QR and 100% visibility.
RFID enabled hide tags	Reader Impinj R440, 4G-router, antenna,	Fresh hides (preliminary test n = 649, main test 1n = 750, main test 2n = 550)	● There is already such a process in place	● RFID tags are only as secure as its fixation to the hide	Hides were tracked between slaughterhouse, hide processor and until the first process of the tannery. Readability: 80% (1st test) and 100% (2nd test).
	Raspberry Pi or Logistic IOT platform.		● Standard off the shelf RFID process ● Ensures the track is kept		

(*continued on next page*)

Table 2 (*continued*)

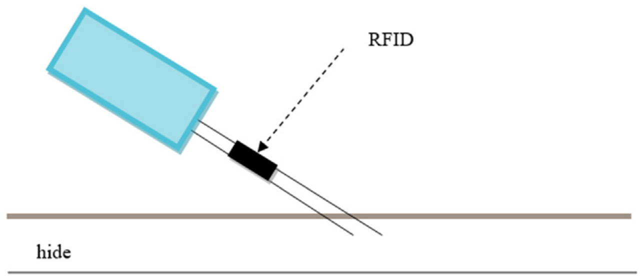

Fig. 4. Injection of Low Frequency RFID tag, usually used for tagging of animals like dogs, into hides.

Fig. 5. Tagging with RFID UHF.

these technologies were sent to a tannery in Italy which shipped them back after the tanning process. The description of each technology and outcomes are detailed in the following sections.

3.3.1. LF RFID Tag

LF RFID was tested to investigate the possibility of injecting tags into biological material. Tags similar to those used for tracking of pets like cats and dogs were injected manually as shown in Fig. 4 using a standard syringe between the outer layers of the hide. Tags were injected into two hides to test the technology and sent to the tannery. The hides were scanned after being returned from the tannery, but the tags were not found. The tags were probably lost or destroyed during the rough tanning process.

3.3.2. UHF Rfid

Conventional radioactively coupled UHF RFID tags were tested using commercial off the shelf labels with Near Field UHF capabilities to overcome the challenges of saltwater and conductivity in hides. UHF RFID was tested as a possible technology for full supply chain traceability. Thus, fresh hides were tagged, allowing the tag to follow the hides through the entire supply chain before checking for the presence of the tags when the hides come back after the tannery. UHF RFID tags were injected into ten fresh hides and sent to the tannery (see Fig. 5) but none of the tags survived the tanning process similar to the LF RFID tags.

3.3.3. Dot peening

Tests with Dot Peening using a portable SIC Marking E1 123 Marking system which is particularly suitable for creating 2D data matrix codes were conducted. Some tanneries also remove parts of the neck, so to ensure the markings are not lost during this process, the tail or farther in the neck area were marked with Dot Peening. Four hides were available to be used for Dot Peening. All hides were marked with the same letters and a QR-code as shown in Fig. 6. In addition to the Dot Peening and white strips, the fresh hides information from the hide tag was collected by photographing the markings so that the information could be linked to the identification numbers, animal ID as well as the time of the marking. While marking the hides it became clear that visibility could become a problem later, as it was impossible to read the markings due to too much fur and blood.

Hides were returned to the hide processor after the tanning process and no marks made with dot peening were found. This was mainly because the hides still had hair when they returned from tanning, making it impossible to find the markings. The hides were shaved to try and locate the markings, but they could not be found. This was attributed to the collagen layer that changes during the tanning process when the hides undergo scraping, warming/drying, stretching and sanding process. This process caused the holes made during the Dot Peening to become blocked. A possible improvement for testing with Dot Peening could be to shave the areas before marking of fresh hides at a suitable step in the processing line. However, delaying the marking to a later stage in the process means missing some of the information generated at the slaughterhouse. Also, shaving the hides before marking adds another processing step that will be time-consuming and add cost.

3.3.4. Laser engraving

A state of the art 30 W MACSA Laser was used for marking of both fresh and salted hides. The goal was to get a machine-readable ID such as a QR code or Datamatrix code on the hide. Secondly, an Alphanumeric ID could be introduced. The hides were engraved at the hide processor and sent to the tannery. The hides were then returned from the tannery and had visible markings (Fig. 7). However, the QR code and the Datamatrix code were unreadable. This was most likely due to deformation of the hides during the tanning process. Despite the difficulties with machine reading of the marks, the laser engraving showed positive results with markings that were still readable after the tanning process. The laser technology could have a potential use in the downstream part of the supply chain (e.g. after the tanning process) and not at the slaughterhouse or the hide processor.

It should also be noted that a hurdle for this technology is the availability of equipment. No handheld equipment has been identified suitable for this job, and an industrial setup is considered to be too cumbersome to use. Another challenge would be to automate the process, as this process was done manually during the current study.

The results from the preliminary tests done using LF RFID tags, UHF RFID tags, laser engraving and dot peening confirmed that the tanning process is the main challenge for these technologies. All these technologies represent marking or tagging the hides' surface directly and all

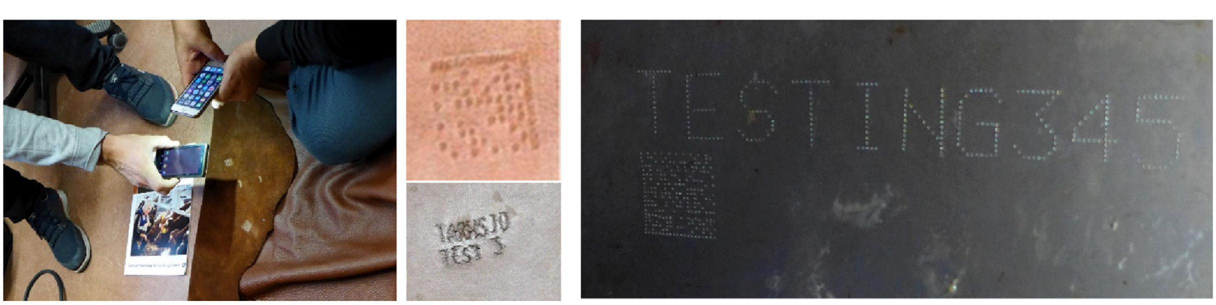

Fig. 6. To the left: Hides were tested in the office prior to entering the facility and tagging fresh hides. Middle: Dot peening on hides after the tannery. Right: Text and QR code printed on the hides using Dot Peening.

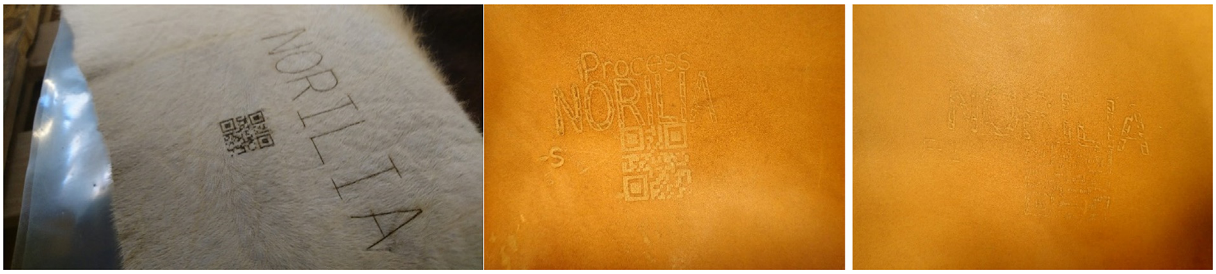

Fig. 7. To the left: Finished hide with markings, the middle and the left shows examples of hides with readable but deformed laser engravings after coming back from the tannery.

Fig. 8. To the left is the hide tag used in production today. The right shows labels with glued RFID tag on one side.

Label Data.

Label Size	48,0x250,8 mm	±0,3 mm	Face material		
Corner Radius	0 mm	±0,1 mm	Liner Type		
Label Pitch	250,8 mm	±0,5 mm	Core Dia.	76,0 mm	
Label Gap	0 mm	±0,5 mm	Labels per reel	750	
Liner Width	0 mm	±1,0 mm	Bad labels mark.		
Caliper incl. IC	,? mm	±20%			

Inlay Data. AD238u8

ISO/IEC	18000-6C		Integrated Circuit	NXP Ucode 8
Type	EPC Class1 Gen2		Operating Frequency	840-960 MHz
Antenna Width	70,0 mm		EPC Size	128 Bits
Antenna Length	14,5 mm		Antenna Material	Aluminum
Web Width	73,2 mm		Antenna Liner Material	Clear Pet
Web Length	17,7 mm	±0,3 mm		

Label Layout. 70%
Inlay attached to wraparound at same side as blackmark

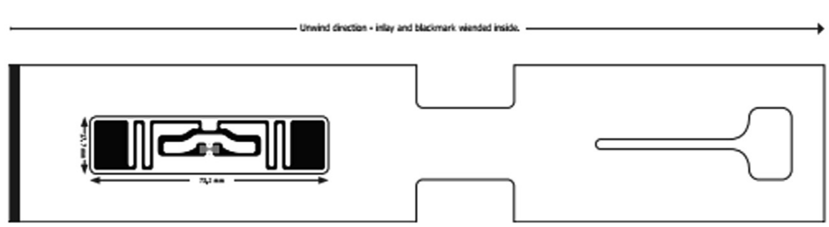

Fig. 9. Specification of RFID enabled hide tags.

of them were adversely affected by the harsh tanning conditions.

To solve this challenge, we decided to test the RFID tags in combination with the existing hide tags. These RFID tags could be glued directly to the existing hide tags used by the hide processor. RFID tags used were *EPC Class 1 Gen 2* which is the most widely used technology and easily accessible to the Norwegian industry. The hide supply chain already uses paper-based hide labels so the additional cost is just the RFID tags that can be glued to these existing hide labels without affecting the surface of the hide directly. These could be used to track the hides up to the tannery. The results from this test are described in the next section.

3.3.5. *RFID enabled hide tags*

Finally, preliminary tests with RFID tagging using existing hide tags were conducted. The equipment tested were traditional hide tags with RFID tags glued to one side as shown in Fig. 8. The detailed technical

Fig. 10. Antennas used at the hide processor during the tests.

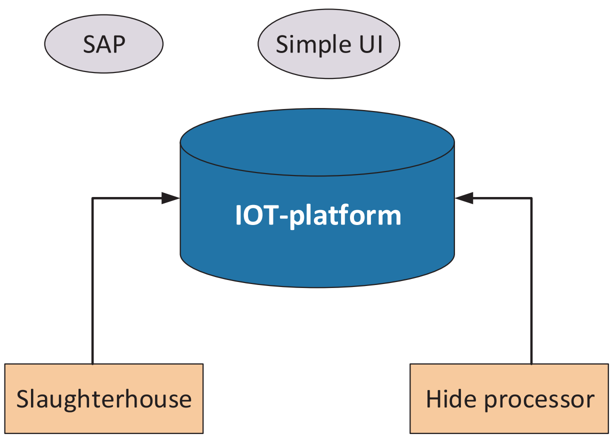

Fig. 11. Test setup for RFID enabled hide tags. The RFID reader supplied data to the cloud via 4G.

specification of RFID enabled hide tags is shown in Fig. 9.

During the preliminary test, 1231 hides were tagged at the slaughterhouse and sent to the hide processor where they were scanned upon arrival at the facility. The preliminary test showed that only about 50% of the tags (616 tags) were registered. The low readability of the tags could be linked to several issues, but the most likely explanation was obstruction of the signals from the RFID chip through the hide. During the preliminary trial several potential causes of the low readability were identified (Table 2).

After the preliminary test, the main pilot tests were conducted on different types of cattle: calf, cow and ox in the slaughterhouse. The RFID labels were glued onto the hide tags after killing and bleeding but before dehiding. The labels were placed about 10–20 cm below the sternum close to the head and neck. Traditionally hide tags have been placed in the throat; however, the placements of the labels have been changed to an area higher up (while the carcass in hanging upside down) to ensure better working condition for workers doing the handling.

The test setup consisted of two waterproof and washable antennas that were mounted at a distance of 2.5 m from the tags. This was done to enable the antennas to cover a larger area as shown in Fig. 10. Additional equipment included a 4G-router and a reader which was placed in a nearby closet. The test setup for reading the tags during arrival at the hide processor was like the one at the slaughterhouse and consisted of one reader and two antennas pointing towards the passing hides (shown in Fig. 10).

The main experiment consisted of two separate tests where the RFID tags were glued onto the hide tags at the slaughterhouse and transported to the hide processor. The first test was conducted using 750 tags and the second test with 550 tags. First test showed good readings and data was sent to the IOT platform for storage as shown in Fig. 11. The tags were read by the RFID reader and real time data was fed into the cloud IOT system including a *readpoint* (the reader and the antenna(s) that read it) and a *timestamp* for the reading. At the slaughterhouse, this generated a *"confirmed working tag attached to a hide"-event* while at the hide processor, this generated a *"hide received and tag still working"-event*. The Vizix IOT platform as well as the open-source Thingsboard platform were used. These enable timeseries data and attributes to be uploaded and linked to the hides and basic reporting like adding locations on maps, table reports and graph/diagram, for example, history of temperature of the hides.

After tagging the hides continued along the processing line. Hides were read again after arrival at the hide processor. After arrival, 649 of the 750 marked hides were readable indicating a readability of about 80%. This was found to be suboptimal. It is probable that the low readability was due to one of the following reasons: hides obstructing the RFID or the antennas were mounted too far away. To improve the readability the antennas were moved closer to the hides on the processing line. The antennas were placed on either side of the conveyor carrying the hides at 1 m and 1.5 m distance respectively. During the second test, all the 550 tags were read at locations ensuring a readability of the RFID enabled hide tags of 100%.

Table 2 provides a summary of the results from the pilot tests.

3.4. TO-BE process map and information framework

After analysing the process and testing the different technologies, a TO-BE process map was suggested for improved information flow in the hide supply chain as shown in Fig. 12.

The TO-BE process map includes the most important process steps and the changes that can be made in order to capture data using RFID enabled hide tags that were successfully tested in the pilot tests. The figure also illustrates the feedback that can be provided to the producer as well as the slaughterhouse based on the classification of hides at the hide processor. This will include information such as slaughter defects or other skin defects or injuries which can be used by the producer to improve their on-farm handling practices and can be used by the slaughterhouse to improve their handling and slaughter processes. With the application of RFID-enabled hide tags, the classification information can be provided for each individual animal which is a significant improvement from how this is carried out today.

3.5. Costs and benefits of proposed technology

An attempt was made to identify the main costs and benefits of the proposed traceability system using different technologies tested in this study. Table 3 outlines the costs associated with the use of dot peening,

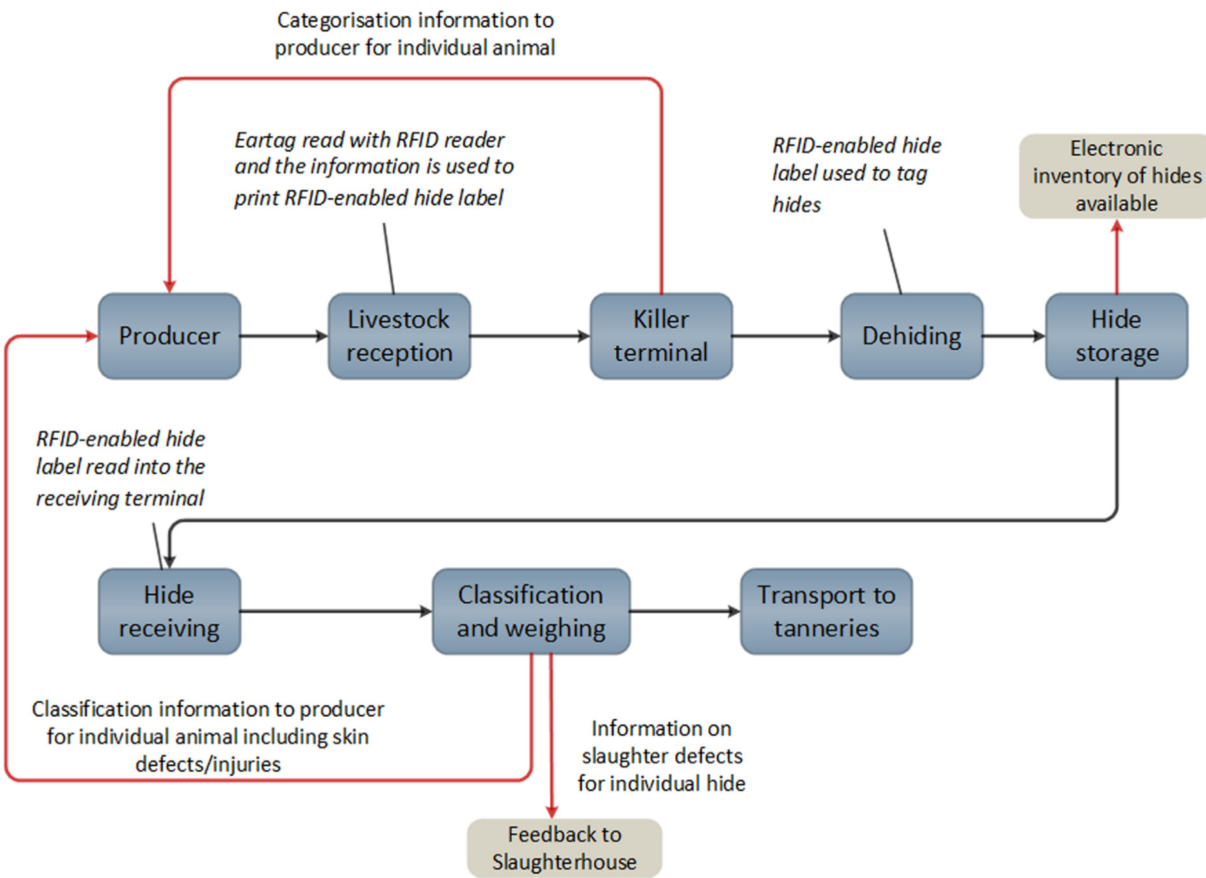

Fig. 12. TO-BE Process map of the slaughterhouse and the hide processor for improved information flow.

Table 3
Costs associated with proposed tagging technologies.

Tagging technology	Equipment used	Cost (NOK)
Dot Peening	SIC Marking E1 123 Marking system	50,000
Laser engraving	30 W MACSA laser	100,000
	Godex GD550 2D barcode reader	3200
RFID enabled hide tags	RFID enabled hide tag	1.00–2.50: combined cost of hide tag and RFID tag depending on volume.
	Reader Impinj R440	0.50–1.00: Just the RFID tag depending on volume
	4G-router	15,000
	Antenna	1000–2000
	Raspberry Pi IOT platform	1000
	Logistic IOT platform	1000
		5000–15,000 per month depending on functionality and number of tags

Table 4
Benefits associated with proposed tagging technologies.

Type of Benefit	Description for present study
Regulatory	Traceability information generated electronically
Internal logistics	No need for manual re-entry of data. Internal operations visibility between the slaughterhouse and hide processor
Recall and risk management	Electronic traceability throughout the supply chain.
Market and customer response	Efficient communication with customers, Origin and quality information linked to specific hides
Supply chain operations	Improved information flow and transparency between supply chain stakeholders. Electronic inventory. Feedback upstream in the supply chain

laser engraving and RFID enabled hide tags that were tested in pilot settings in this study. In addition to the cost of the equipment, other costs related to implementation would also include training for the staff.

Estimating quantitative benefits of these technologies is more complicated without implementing them in the real-world. We used the framework developed by Sparling and Sterling (2004) and a summary of qualitative benefits is presented in Table 4.

4. Discussion and future work

Several data capture technologies for traceability of hides were tested in this study. Two of the tested RFID technologies, UHF RFID and LF RFID tags couldn't be located in the hides after the tanning process and were presumed to be lost or destroyed during handling or processing. Further, the hides used for testing dot peening came back after the tannery with hair, which made it difficult to read the markings. Hides marked with laser engraving showed promise, and despite distortion the engraved text was still readable after the tannery. However, of all the different technologies tested the RFID enabled hide tags provided best readability before tanning while there were challenges with the other technologies. The RFID tags were used for tracking between the slaughterhouse and the hide processor. In theory, all tags and markings tested in the study are readable, but the tanning process is the main challenge for the available technologies.

In any case, reliable traceability from the farm to the hide plant is possible with all the technologies tested, of which the RFID tags proved to be most suitable. If the machine-readable requirement is not essential, laser engraving can be used for traceability also including the tanning process. Manual inspection of hides marked with laser engravings would still be possible. Thus, the best current solution would be to employ RFID enabled hide tags from the slaughterhouse until the tanneries. After the tanning process, laser engraving of the hides with an alphanumerical code could be used which would be machine readable. This enables tracking of the hides up throughout the supply chain and the information captured can be used in several ways, for example, differentiating their products in the market by providing origin information to the customers.

The suggested TO-BE process map would lead to improved information flow and thus leading to better coordination between the supply chain partners. Using the RFID-enabled hide tags makes it possible to link the hides to specific farm and can be used for authentication of hides and can be useful for providing product information to the end customers, in turn differentiating the products in the market.

The data generated through the supply chain from quality inspections can be used as a feedback to the producers and in turn can be used to improve the handling practices on the farm as well as during the transport and slaughter of animals. Additionally, tracking of the hides and online readings can help with providing an overview of the contents of, for example, cold storage rooms, and prevent hides being stored too long. Introduction of a traceability system like the proposed in this study will also enable for data collection and further possibilities related to BigData and Artificial Intelligence (AI). Temperature monitoring using RFID-enabled tags could be used in combination of traceability for quality control.

AI applications could be used to analyse the large volumes of data captured throughout the supply chain and can be used for decision making by various supply chain actors. Another use case can be the application of computer vision in combination with laser engravings that can eliminate the need for manual inspection and tracking of hides. At each stage of the supply chain, computer vision can be used to check the quality of individual hides connected to their unique IDs and send this information to the relevant actor. Any problems can be detected immediately and corrected.

Security concerns related to the use of RFID tags should be taken into consideration when developing the traceability system. Security risks must be assessed and mitigated during the deployment process. The RFID tags and the data can be protected in several ways:

(1) Tags can be locked permanently or with a password so they cannot be altered.
(2) Tags have a Transponder ID (TID) which is globally unique and is *read only*. By keeping a database of the TID and the corresponding EPC, it is possible to determine by reading both the elements if the tag is authentic. Industries such as pharmaceutical and fashion use this method. Altering the TID is not possible, and the only way to be able to define which TID to have inside a chip is by owning a chip production plant which is a huge investment. So far nobody has been able to penetrate this security layer.
(3) Another method which can be used in combination with others is using randomized serial numbers. Since in 96 Bit UHF tags, there are 194 billion potential serial numbers, by not using the serial numbers sequentially, but randomized, it is likely that a fake product either collides with a real serial number on a wrong place in the supply chain, for example, a product that was manufactured and sold two years ago suddenly turns up in a store with records that show it is straight from the manufacturer will raise an alert.
(4) Application of blockchain combined with RFID tags can help secure the data. Blockchain in its core sense is a database, which is spread between many computers to avoid intermediaries and allow for peer-to-peer interactions. There is no central authority that governs the whole process and alteration of data is almost impossible, which provides transparency and traceability of transactions and data either for members of the chain or for the public, respectively.

Finally, the supply chain actors need to be share information in order to achieve an efficient supply chain but the willingness to do so remains a challenge. The Norwegian hide supply chain (producers/farmers, slaughterhouse and hide processor) presented in this study is vertically integrated, the slaughterhouse is producer-owned company and the hide processor represents a daughter company. Therefore, there are no problems related to data sharing. In case of non-integrated supply chains, the mutual benefit of sharing information needs to be understood by all supply chain actors which can encourage them to collaborate.

CRediT authorship contribution statement

Maitri Thakur: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Project administration. **Guro Møen Tveit:** Writing - original draft, Investigation, Writing - review & editing. **Geir Vevle:** Investigation, Software, Validation. **Tufan Yurt:** Investigation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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