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e-Bale: The Potential Radio Frequency Identification of Wool Bales

By

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0. SUMMARY

The wool industry commenced its investigations into the electronic (radio frequency) identification of wool bales in the 1980s and 1990s. The electronic bale identification (e-Bale) concept was last trialled by the Australian Wool Exchange Ltd (AWEX) in 2007 and since that time the technologies have become more sophisticated and are being produced at a much lower cost. A desktop review conducted in 2013 determined that RFID tags, potentially suited for use in the wool industry, were available at a price point of less than US$1.

A Cost/Benefit Analysis (CBA) of e-Bale based on 2005/06 information was undertaken with positive benefits identified. This CBA was updated for 2013/14, since the circumstances of wool production and handling were different, with a reduction in sheep numbers and the restructuring of wool broking and handling companies. The 2014 CBA concluded that significant industry benefits could be gained from the implementation of RFID technology. Benefits that may be achieved from e-Bale include:

- Improved supply chain traceability and quality control.
- Improved information flow from farm to processing mill, including the accurate identification of bales.
- Enhanced performance of Electronic Wool Classer's Specifications (WoolClip) – information direct to store.
- Rapid identification of wool bales in the event of an Exotic Animal Disease outbreak, which is of value when preparing for and/or responding to such a situation.
- Improved downstream efficiency and quality management to maintain the price and position of wool in a competitive textile market.
- Enhanced reputation of the Australian wool industry for quality and innovation.

It is recognised that "industry good" projects are often undertaken with wool growers bearing some or all of the costs. The introduction of e-Bale to the wool industry would see benefits accrue to downstream users with potential for some or all benefits to be shared with wool growers. Wool growers are already paying for the current inefficiencies in the wool pipeline; and hence, improvements in wool handling and distribution through the introduction of RFID will directly and/or indirectly benefit them.

Actual benefits to the grower may be achieved through the linkage between WoolClip and RFID tagged bales, which would ensure that all bales are uniquely identifiable. A hand-held reader may also be used to identify bales as they are loaded onto a truck, with all bales on the truck read as it is driven through/past a "portal" comprising fixed antennas and reader at the wool store.

Based on this knowledge, AWEX re-commenced its work to evaluate the available technologies and trial them through the wool pipeline. The strong interest of the wool industry was demonstrated by the financial and in-kind support received from AWH Pty Ltd (Australia's largest wool handling and logistics company). In-kind support for the Farm to Store trials was received from wool brokers Elders Ltd and Moses and Son and their wool growing clients. New England Wool and Modiano Australia purchased wool for their mills in Biella, Italy and Nejdek, Czech Republic, respectively, with all four companies contributing to the conduct of the Store to Mill trials.

Between 2013 and 2015, trials were undertaken to assess if any commercial or experimental tags could survive the dumping process and be read in a tripak. Testing the tags through the dump was essential as this is harshest environment in the wool supply chain. Once potential tags were identified, subsequent trials evaluated them from farm to wool store (with WoolClip used to log each bale with an RFID tag), and as well, from the wool store to European processing mills.

This paper describes the e-Bale project and trials conducted by AWEX in collaboration with stakeholders that resulted in the identification of a preferred RFID tag for the wool industry. It also details specific applications that may be achieved by e-Bale along the wool supply chain including on farm, land transport, wool storage, wool sampling, wool dumping, containerisation, shipping and at the mill. The benefits at each point may include the accurate and rapid identification of bales, improved information flow, efficient handling and storage, as well as enhanced quality control.

1. INTRODUCTION

Based on the significant improvements and cost-savings to the handling and distribution of other materials and products, the wool industry has been investigating machine-readable systems for wool bales since the 1980/90s. However, the wool pipeline is complex involving many challenging environments; for example, the dump (where 2 or 3 bales are compressed into the size of one bale, i.e. a double or tri-pak, respectively, and contained using metal straps); and therefore, technologies cannot simply be transferred from another industry. Investigations into the electronic identification of wool bales were undertaken with two projects acknowledged as bringing core information to the research. These were: Intrawool (2000) – Wool bale identification: evolution from hand stencil to transponder and Creative Logistics (2003) – Pilot industrial trial of electronic bale identification.

One and two-dimensional Barcodes printed onto wool pack labels were trialled by the Australian Wool Exchange (AWEX) in Australia commencing in 2000; however, no permanent application resulted and they were subsequently removed from the label in 2009 (AWEX, 2015). The main reasons Barcodes were not adopted was due to the difficulty reading the Barcodes if the pack label was wrinkled or obstructed, and they could not be read once bales were dumped into a tri-pak/double. Thus, the Barcode had limited use.

Despite the failure of Barcodes, the Australian wool industry continued its investigations into machine readable identification systems due to the specific benefits that might be achieved, viz.:

- Improved supply chain traceability and quality control.
- Improved information flow from farm to processing mill, including accurate identification of bales.
- Enhanced performance of Electronic Wool Classer's Specifications (AWEX released "WoolClip" software to the wool industry in 2014) – capable of providing information direct from farm to store.
- Rapid identification of wool bales in the event of an Exotic Animal Disease outbreak, which is of value when preparing for and/or responding to such a situation.
- Improved downstream efficiency and quality management to maintain the price and position of wool in a competitive textile market.
- Enhanced reputation of the Australian wool industry for quality and innovation.

AWEX's involvement in the application of electronic technologies to the identification of wool bales has included contributions to the Intrawool project conducted during the late 1990s (Intrawool, 2000), undertaking an assessment of Radio Frequency Identification (RFID) (Schmitt, 2006), and subsequently conducting preliminary trials to evaluate RFID of wool bales, viz. Swain (2006) and Hansford (2007). AWEX's investigations into the electronic identification of wool bales were entitled "e-Bale".

The Schmitt report (2006) comprised two main elements: an evaluation of available technology and a Cost/Benefit Analysis (CBA) of RFID. When evaluating the radio frequency most appropriate for the wool industry, this report and others (Intrawool, 2000; Creative Logistics 2003) considered transponders (tags comprising a chip and antenna), of Low Frequency (LF), which is used in the National Livestock Identification Scheme for cattle and sheep, and Dual Frequency (DF). Of primary consideration was that:

- The tags could be read at a distance of >2 m,
- The tags could survive dumping and be read in a tri-pak (despite interference from compressed wool, moisture and metal),
- Multiple tags could be read simultaneously (anti-collision), and
- The tags would be available at a price of <US$1 each.
- It was noted that the standardisation of tag type across the entire wool industry was also seen as critical to keep costs to a minimum.

Ultimately, LF tags were not suitable as their read range is <2 m and they do not have multiple tag read ability. Swain's investigation (2006) of DF tags indicated that there were failure rates in reading the tags of 1% - 7% from farm to store to post-coring, with these failures expected to increase as the bales travelled through the dump, shipping and to the mill. Follow up trials using a "credit card" DF tag were undertaken (Hansford, 2007). In this case, the tags were adhered under the pack label at the pack manufacturing plant. The study found that 96% of tags could be read while the packs were still in their bundles of 50 packs, while 98.5% could be read once the bundles were open. After pressing these RFID packs with wool and coring the bales, the tag read rate was 98%, with this reducing to 92% after dumping. This poor read rate, likely due to the significant physical damage to the tags observed after they had been removed from the dumped bales, led to the termination of this study.

The second element of the Schmitt report was a CBA based on 2005/2006 information. Dumping is the most intensive challenge to RFID technologies in the logistic chain and it is essential that the dumped bales can be read; however, year to year the % of bales dumped varies based on shipping costs. For example, currently most wool sold into China is not dumped, while most wool sold in to Europe is dumped. While the differences in the rates of dumping are important, it is not envisaged that they will dilute the potential benefits of the introduction of e-Bale to the pipeline.

Simplistically, the 2006 analysis was based on 100% industry adoption, 2.6 m bales per year and a 7 day reduction in the wool pipeline. Based on Australian $ values, it found:

- A Direct Net Benefit of $1.16 per bale may be achieved.
- An annual net saving in logistics costs of $3.1 million may be made. This does not take into account other potential benefits such as removing the need for countermarking.
- A potential saving of up to $1 per bale for the removal of countermarking, a practice that while necessary, is known to cause problems.
- A potential reduction in working capital costs of up to $0.94 per bale (or $2.5 million across the industry) by streamlining the delivery of wool from farm to mill.

2014 presented different circumstances in terms of wool production and wool handling, with a well-documented reduction in sheep numbers (Australian Wool Innovation, 2015) and the merging/restructuring of wool broking and handling companies. With this in mind, a CBA of RFID was undertaken (Wilcox, 2014) to update the findings of the 2006 analysis. The 2014 analysis used an updated version of the 2006 cost model, which was modified based on advice from the various sectors.

The 2014 analyses breaks down the broking sector into large broker/wool handler (approx. 59% of Australian Clip), medium brokers (approx. 22% of Australian clip, or each broker handles 30,000 bales or more per year) and small brokers (approx. 19% of Australian clip, or each broker handles less than 30,000 bales per year). It is assumed that the per bale cost savings for early stage processors are the same as for dumps. The 2014 analysis was based on 81% industry adoption and 1.8 million bales per year. Table 1 presents a comparison of the 2014 and 2006 savings per bale.

Table 1 Savings per bale by stage/sector – 2014 compared with 2006

Stage	2014 Savings ($/bale)	2006 Savings ($/bale)
Pre-Sale		
Large broker/wool handler	$2.03	$1.52
Medium brokers	$1.95	
Small brokers/private treaty	$1.83	
Post-Sale		
Large broker/wool handler	$0.12[1]	
Medium brokers	$0.12[1]	
Small brokers/private treaty	$0.09[1]	
Post-sale with automated countermarking (large broker)	$0.51	$0.38
Total wool handling		$1.73[2]
Large broker/wool handler	$2.15	
Medium brokers	$2.07	$1.54[2]
Small brokers/private treaty	$1.92	
Total with automated countermarking (large broker)	$2.53	$1.90[2]
Dumping	+$0.67	$0.52
Australian early stage processing	+$0.67	$0.28

[1] No savings in automated counter-marking included [2] Savings from countermarking included

Where comparisons were available, Table 1 shows that the savings per bale have increased. For example, for a large broker/wool handler, pre-sale savings have increased by 51 c/bale, while post-sale savings (with automated countermarking included) have increased by 13 c/bale. These increases in savings are largely due to the increased costs since 2006. There has also been an increase in the savings per bale estimated for dumping, which is attributable to an increase in the operational costs of dumps since 2006.

Based on perceived improvements in RFID technology; in 2013, AWEX commissioned a desktop review of state of the art RFID technologies (Karmaker, 2013). This review confirmed that RFID technologies potentially suited for use in the wool industry were now available, with chipped tags[#] being produced at a much lower cost. Therefore, based on this knowledge, AWEX believed it was timely to re-evaluate the available technologies and trial them through the wool pipeline. This decision was subsequently supported by the revised CBA (Wilcox, 2014), which determined that significant benefits could be achieved through implementing RFID technology.

It has been noted; however, that "industry good" projects usually require wool growers to bear some or all of the cost/investment. The introduction of e-Bale to the wool industry would see most of the benefits accrue to downstream users. That said, wool growers are already paying for the current inefficiencies in the wool pipeline; and therefore, improvements in wool handling and distribution through the introduction of e-Bale would indirectly benefit growers. Actual benefits to the grower may be achieved as follows:

- Potential incentives from brokers/wool handling facilities,
- Linkage between an electronic Wool Classer's Specification (WoolClip) and RFID tagged bales would ensure that all bales are identified and described correctly,
- Identify bales as they are loaded onto a truck and subsequently received at the wool store,
- Reporting/reconciliation and traceability benefits, and
- Potential biosecurity benefits.

[#] Chipless RFID tags were also identified as being suitable for the industry and potentially at a very low price; however, it was considered too premature in their development to warrant further investigation at this time. Should chipless RFID become commercially viable in the future, the transition to its use would be easier if chipped RFID technology had already been introduced.

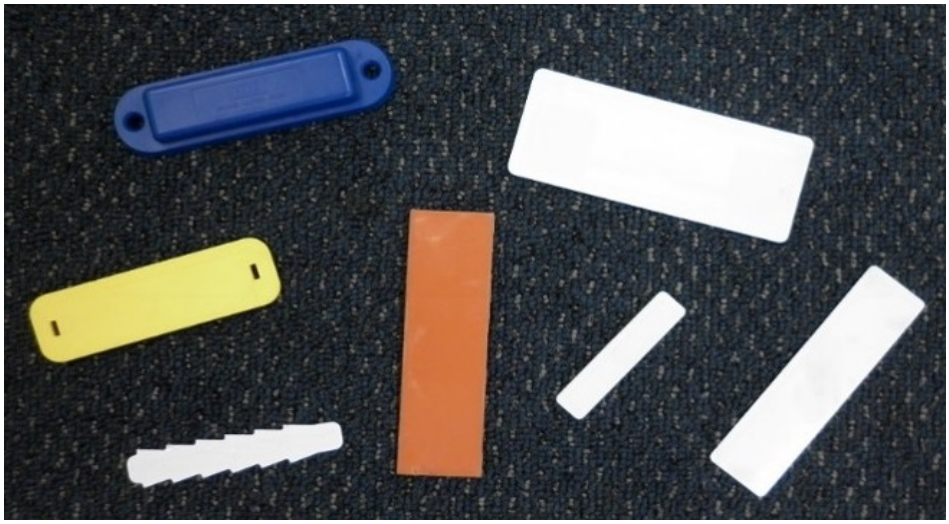
2. MATERIALS AND METHODS

2.1 Trials to Identify Suitable Tags

In 2013/14, AWEX with the support of AWH Pty Ltd (AWH) conducted trials at their wool store in Brooklyn, Victoria on a variety of Ultra High Frequency (UHF) passive tags provided by different suppliers/manufacturers (see Photo 1). Passive tags do not have a battery, rather they rely on the reader as their power source, and are manufactured to be disposable. The tags included commercial as well as experimental tags produced by the manufacturers to meet the wool industry's requirements.

The selection trials aimed to evaluate the performance of different tags at the harshest point along the wool pipeline: the dump. The pack label (see Photo 2) was used as the carrier for the tags as this is the least damaging position when three bales are compressed into a tri-pak. Tags were tested across a range of wool types, (e.g. Merino and Crossbred fleece/pieces), bale and tri-pak weights, temperature and humidity.

Photo 1: Examples of different RFID tag types



The RFID tag must work in an environment comprising (highly compressed) wool, moisture and metal. Therefore, the selection trials involved testing the best combination of inlay (comprising a chip and an antenna) and packaging (which protects the inlay, e.g. plastic, silicon, nylon, ceramics, wire etc.), whilst also considering price. From these preliminary studies through the dump, two experimental RFID tag types were chosen for whole of pipeline evaluation.

2.2 Whole of Pipeline Study

There is a disconnect between the sectors of the wool pipeline (i.e. farm bales combined into sale lots may be purchased by different buying companies); therefore, the trials were conducted in two parts.

2.2.1 Part 1: Pack Manufacturer, Farm to Store Trials

The Farm to Store trials involved the following stages: pack manufacture with RFID tag attached, shearing shed, transportation, movement by forklifts, storage and core/grab sampling. Both Merino and Crossbred wool was used in these trials since Merino wool is the predominant breed of sheep and wool type produced in Australia, while Crossbred bales are more difficult to read when dumped, most likely due to its higher moisture (and grease) content. The higher moisture content of Crossbred wool compared to Merino wool has been previously described (Young, 1955).

(a) Equipment

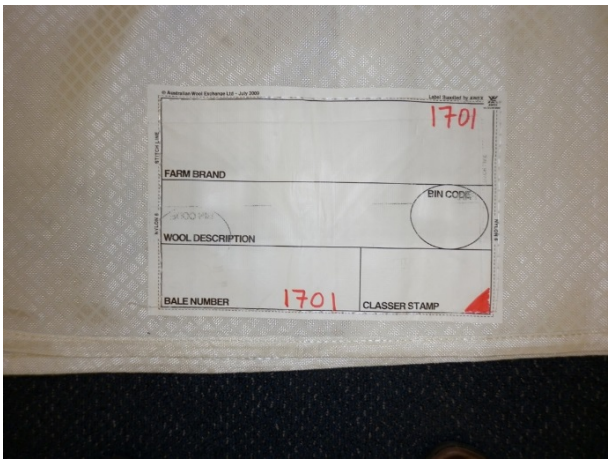
AWEX arranged for a total of 2,000 experimental RFID tags (1,000 of each type) to be adhered to the underside of pack labels (see Photo 2) with the Unique Tag Id also hand-written on the outside of the pack label as a back-up (see Photo 3). The labels were sent to a pack manufacturer in Asia, where they were sewn onto the packs and the packs shipped back to Australia. All tags (100%) read on arrival in Australia – both in their bundles of 50 and once the bundles had been opened.

Fixed antennas and readers were set up as required. Hand-held readers were the primary tool used to read the tags.

AWEX's Electronic Wool Classing software (WoolClip) was modified to enable the RFID tagged bales to be scanned into the program and stored against a Bale Number and Description and the line of wool.

Photo 2: RFID tag adhered under a pack label

Photo 3: Back-up Identification on Pack Label



(b) Farm to Store Trial Participants, Tag Reading and Data Capture

With the support of AWH, Elders Ltd and Moses and Son (and their clients), the Farm to Store trials were conducted in two parts, with following activities undertaken to compare the performance of the two tag types and to trial the link between the tags and an Electronic Wool Classer's Specification:

i. Bales of wool were delivered to the AWH facilities, Brooklyn from six Elders Ltd client's farms in Victoria. The aim was to determine the survival rate of tags from farm to store, with Merino and Crossbred wool types, bale weights (low and high) and atmospheric conditions (different temperatures and humidity) evaluated.

   The bales/tags were read on arrival at the wool store on a truck using a hand-held reader (see Photo 4) and when the truck was driven past a "portal" of fixed antennas and reader (see Photo 5). They were subsequently read in their stacks after core/grab sampling using a hand-held reader.

Photo 4: Reading bales while loaded on a truck

Photo 5: Truck driven past the portal

ii. Bales of wool were delivered to Moses and Son, Temora from three client's farms in NSW. The aim was to prove the concept of recording the Unique Tag Id of RFID bales in a shearing shed using AWEX's Electronic Wool Classing software (WoolClip), and identifying each bale on arrival at the wool store and after core/grab sampling.

The bales/tags were read in the wool press after the packs were closed (see Photo 6), with the Unique Tag Id transmitted to the WoolClip software (see Photo 7). Note the use of a small, lower cost hand-held reader that has a shorter read range more suited to on farm use. All the bales were subsequently read on arrival at the wool store.

Photo 6: Scanning RFID Tag Id of bale in wool press

Photo 7: WoolClip receiving RFID Tag Id

2.2.2 Part 2: Store, Dump to Mill Trials

The Store to Mill concept involved testing RFID tags through the following stages: pre- and post-dumping, containerisation, shipping and at the mill.

(a) Equipment

A 1-Watt hand-held reader set to the Australian UHF bandwidth was used to read the bales and the tri-paks at AWH. Information on each bale held on the AWH database was transmitted to the reader, with this information being presented when each tag was scanned (see Photos 8 and 9). At the two mills, a second 1-Watt handheld reader set to the European UHF bandwidth was used. This bandwidth is slightly different to that used in Australia.

At AWH, an antenna connected to a reader and computer, was mounted on a gantry above the conveyor to the dump (see Photo 10). A software program was developed to link three bales in a tri-pak, such that if one bale in a tri-pak could be read, the others would be known by association (see Photo 11).

Photo 8: Hand-held reader used in-store/mills

Photo 9: Programmed hand-held reader

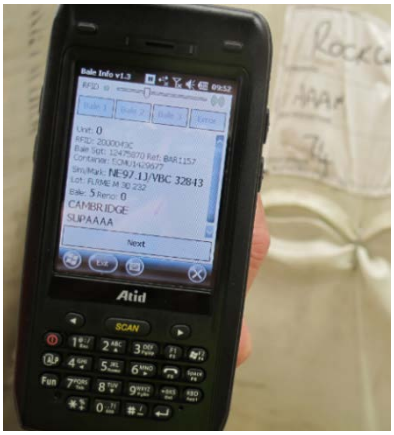
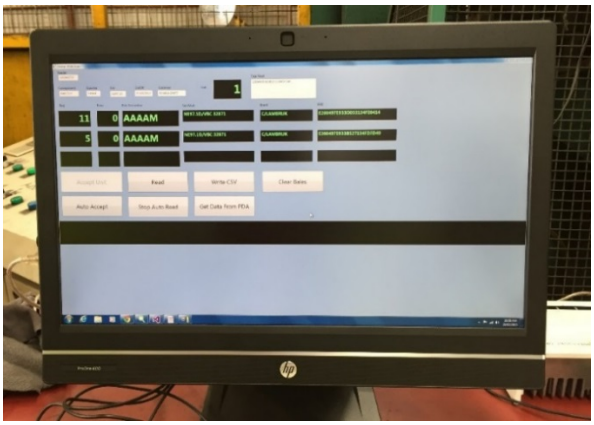


Photo 10: Bale passing under RFID antenna

Photo 11: Bales being linked into a tri-pak unit



(b) Store to Mill Trial Participants, Tag Reading and Data Capture

For the Store to Mill trials, AWH contributed in-kind and financially including the use of their dump and the development of software. The wool exporters: New England Wool purchased Merino wool (342 bales) for Pettinatura Romagnano, Italy and Modiano Australia purchased Crossbred wool (758 bales) for Nejdek Wool Combing, Czech Republic. These exporters either buy for their own mill or have a close relationship with it, thus providing greater control of the trials, especially when the wool arrives at the mill. The following activities were undertaken to compare the performance of the two tag types:

i. At the AWH warehouse, the tags were inserted under the pack label and the Unique Tag Id associated with the bale information (e.g. Brand, Bale No., Wool Type, Lot No., Countermark, etc.) held on the AWH database. Bales were read with a hand-held reader.

ii. Before the dump, each set of three bales was read using the fixed antenna/reader prior to entering the dump and allocated a tri-pak Unit Number.

iii. At the mill, the tri-paks were read using hand-held readers after unloading the container but before opening the tri-pak. If any tag did not read in its tri-pak, the tri-pak was opened to see if the tag(s) could be read or not.

3. RESULTS AND DISCUSSION

3.1 Whole of Pipeline Study

Based on the Materials and Methods described above, the results of the Whole of Pipeline trials using two experimental RFID tag types were as follows.

3.1.1 Part 1: Pack Manufacturer, Farm to Store Trials

Six Victorian wool growers (both Crossbred and Merino) used a total of 750 RFID tagged packs comprising 50:50 of each type. Post-shearing they delivered their bales to AWH, Brooklyn, Victoria with all tags (100%) reading both in store and after core/grab sampling; and accordingly, there was no discernible difference in the performance of the two tags types from Farm to Store.

The tags could be read through stacks, at a distance of up to 10 m, depending on wool type. One bale read from a much shorter distance (½ m); its pack label and tag was found to have a "hole" in it, most likely from a bale hook. Note, damage to the antenna of the tag may reduce the read range but does not necessarily "kill" the tag, whereas if the chip is damaged or the connection between the chip and the antenna is broken, the tag will not read. As shown in Photo 2 (above), the RFID tags adhered strongly to the pack label, such that if the label is partially ripped from the pack, it may still be possible to read the tag.

Reading tags (attached to bales) from a distance of up to 10 m has important implications for locating bales within a wool store. A reader may be programmed to search for a specific Unique Tag Id, while ignoring all other Tag Ids. It is also possible to store bales in locations (e.g. rows, stacks) that have their own RFID identifier (e.g. a RFID transponder in the floor), thus a link may be formed between bales and their location.

Tests were conducted to assess whether tags could be read as a loaded truck drove through/past a "portal" comprising antennas attached to a reader. Using trucks of different sizes (e.g. 2 or 3 layers of bales), for six test runs, 97 - 99% of bales read. Based on two additional tests, it was confirmed that if the antennas were re-positioned and/or extra antennas added, it was possible to read 100% of bales on a truck driven at ~10 km/hour. Curtains on a truck did not seem to affect tag reading.

Approximately 300 bales of wool from three client's farms were delivered to the Moses and Son's wool store in Temora, NSW. All tags (bales) were captured by the WoolClip software in the shearing shed and read on arrival at the wool store. In the future, the WoolClip Classer's Specification would be electronically transmitted (e.g. emailed) direct to the store prior to the wool arriving. This would eliminate the need for the Classer's Specification to be re-entered by wool broking staff; and hence, minimise data entry errors.

It is anticipated that e-Bale would be of benefit to the core and grab sampling of bales/lots and their subsequent measurement, with the Unique Tag Id offering improved traceability, quality control and information flow.

3.1.2 Part 2: Store, Dump to Mill Trials

During the trials, not all bales in each tri-pak were linked due to the breakdown of dumps and issues with the trial software; however, sufficient bales were linked to demonstrate the concept that if one bale in a tri-pak could be read, then the other two bales are known by association.

At Romagnano, for 342 Merino bales, 341 tags were read in approximately 110 tri-paks plus doubles and singles using the hand-held devices, even when the tri-pak weight was ~600 kg. One tag was damaged and would not read at all.

At Nejdek, for 758 Crossbred bales, 752 were read in approximately 250 tri-paks plus doubles and singles. Six tags were damaged and would not read at all. In addition, no tag could be read in six tri-paks (excluding the six damaged tags); however, all tags read when the tri-paks were turned over and/or opened.

Photo 12 shows bales and tri-paks laid out for reading (and/or in storage) at Romagnano, Italy while Photo 13 shows a tri-pak being read using a hand-held reader at Nejdek, Czech Republic.

Photo 12: Bales/tri-paks laid out at Romagnano

Photo 13: Reading tri-paks at Nejdek

The results of the trials differeniated between the two tag types, viz. 100% of one tag type read, while seven tags (1.3%) of the other type were damaged and could not be read. Therefore, the AWEX trials identified a preferred RFID tag for use in the wool industry. There was no difference in the performance of the two hand-held readers, which used different band-widths, since they both read the same tags in all the tri-paks.

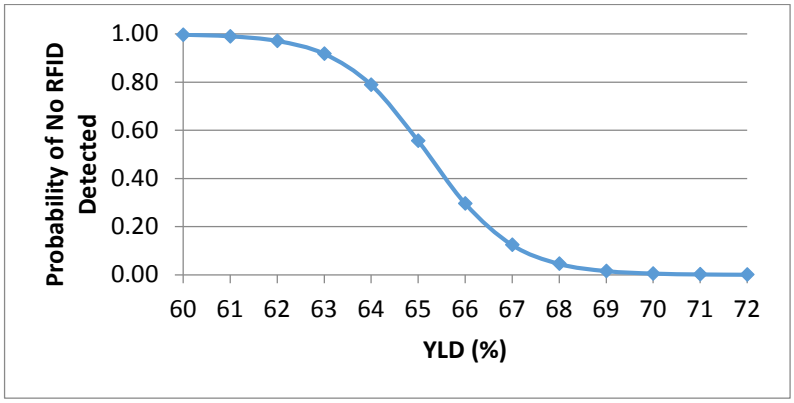
(a) Analysis of Tri-paks that did not Read

As reported in 3.1.2 above, no tag could be read in a small number of Crossbred tri-paks at Nejdek; however, they read once the tri-paks were turned over or opened. The raw wool data was collated for each bale and analysed to determine if any variables were associated with a tri-pak reading or not (Wohlers, 2015). The variables considered were: Mean Fibre Diameter (MFD), Yield (YLD), Fibre Curvature (CURV), Staple Length (SL), Vegetable Matter Base (VMB) plus Tri-pak Weight (Tri-pak Wt).

Plotting the "0 (zero) reads" against 1, 2 or 3 tags reading revealed that the tri-paks that did not read contained low YLD wool. In contrast, for the other variables there was overlap between tri-paks where 0, 1, 2, 3 bales read (see Appendix 1 for plots of each variable).

A linear model was used to further evaluate the data, with YLD being the only statistically significant parameter (P = 0.005); i.e. the lower the YLD, the harder the tri-paks were to read (see Graph 1). Although they were not statistically significant, there was also a trend for the tags that did not read to be in heavy tri-paks containing wool that was higher in MFD.

Graph 1 YLD as a Predictor of No RFID Tag Reads



It should be noted that this data set is small, with only 7 no reads. Given the strong significance of YLD in the modelling, it is likely that this parameter would continue to have an effect even if a larger dataset was available.

From this analysis, it appears that whether a Crossbred tri-pak will read or not is largely dependent on YLD and to a lesser extent (coarse) MFD with a heavy Tripak Wt. The incidence of this set of criteria (low YLD, coarse MFD and heavy Tri-pak Wt) in dumped Australian wool exports is not very common.

4. OTHER MATTERS

In addition to the points raised in the Results and Discussion above, there are a number of other matters related to e-Bale that are relevant to this paper. For information purposes, some of these matters are briefly discussed below.

4.1 Standard RFID Tag for the International Wool Industry

The performance of RFID technology has improved greatly over recent years with the cost of tags and associated equipment decreasing. That said, the current price point of <US$1 per tag is based on an order of 1.5 million tags over 12 months, with very slight reductions in price available if higher tag numbers are ordered (e.g. 2.5 or 3.5 million tags). Obviously, the price is affected by the value of the US$.

AWEX, through a single purchase order, is in a position to implement an international "unique wool RFID tag" that would facilitate its introduction to all wool industry sectors, in all countries. For example, the Unique Tag Id for each bale (or other wool unit such as a bump) could include the following masks: "AWEX"; "Wool Type" (greasy, top, yarn etc.); "Country" followed by a sequential Unique Tag Identifier. Masks are extremely important as they are the mechanism to differentiate the tags on wool bales from RFID tags on other objects/products in proximity to the bales. Given hand-held readers can read the preferred e-Bale tag at a distance of up to 10 m, this is of great value.

It is also important to note that security of the Unique Tag Id is available by a cross-check with the Tag Identification Number (TID) that is applied to the chip at its manufacture. The TID cannot be changed or deleted. This cross-check will ensure that if a theft has occurred and a counterfeit RFID tag applied, the stolen bale will be recognised as non-compliant enabling its transfer through the pipeline to be blocked.

As previously indicated, the preferred AWEX tag is passive (activated by a reader). It does not store large amounts of information as it is intended that this is accessed via the standard databases currently used by the wool industry.

However, the RFID tag preferred by AWEX does have additional memory that may be utilised by industry; for example, a shipping countermark may be written to the tags. This separate, "broker/warehouse" derived code could be written to the tag in the wool store to enable accurate identification of bales to be dumped and shipped, with these Unique Tag Ids/Codes subsequently used during containerisation, shipping, storage and delivery to mills. Equally, a separate, "mill" derived code may also be applied for quality assurance purposes.

4.2 Back-up Identification of Bales (other Wool Units)

In considering the e-Bale concept, AWEX felt it important to ensure that back-up identification for each Unique Tag Id was available. To this end, it is envisaged that the pack label would have the same Unique Tag Id printed on it as Alpha/Numeric characters as well as a Barcode. Although the adhesion of the tag to the label is strong, the label would provide back-up identification. The advantage is two-fold: it would provide back-up identification if the tag is lost/damaged and/or the Barcode could be used on farm (or in store) instead of the RFID tag. Since smart phones now have Barcode reading technology, this could reduce the set-up cost for on farm use.

The same tags could also be adhered to the outside of the pack label or to the different types of greasy wool packaging used in other countries. The tags may also have application to the packaging used for bumps or other processed wool products. It is possible to print the Unique Tag Id as a Barcode on the packaging of the tag (at extra cost). Should the technology be adopted industry wide, adhering tags to the outside of a pack label on bales at a wool store would be necessary as an interim measure while packs without RFID tags are phased out.

4.3 Improved RFID Technology

As mentioned, RFID technology is rapidly improving. By standardising the tag type, if incremental improvements to the tag (chip, antenna and/or packaging) are made, they could be readily implemented across the entire wool industry.

Equally, reader technology is also advancing. Basic hand-held readers come with wireless LAN and RFID scanning capability; however, they also have options such as the ability to read Barcodes, 3G phone and internet access, GPS capability, Bluetooth and USB connections, and/or camera and flash. At present, they are usually Windows CE or Windows Mobile based; however, Android is increasing in popularity since it is web-friendly.

It is worth noting that since the mill trials were conducted in early 2015, due to improvements to the antenna, the power of 1 Watt hand-held readers has increased by ~50%, which would most likely improve the ability to read low yielding Crossbred tri-paks.

5. CONCLUSIONS

5.1 Feedback from the Trial Participants

AWH and Moses and Son were both positive about the potential benefits of e-Bale as per their feedback:

> Marty Moses, Moses and Son, Australia
>
> *For Moses & Son's wool broking division, the e-Bale project is the cornerstone to a more efficient warehousing system. I can see RFID technology and the development of automated handling systems integral in driving the cost of wool warehousing down in time, and that is comforting news for our sector. Even better news is that the processors are already expressing interest in the technology. Essentially, on the question of full implementation, the answer is more likely to be "When" than "If"!*
>
> John Payne, AWH Pty Ltd, Australia
>
> *AWH has been pleased to be a participant and supporter of the trials to date of the e-Bale project. The success of the tag viability through our wool dumps was an important step toward a robust unique bale ID system.*
>
> *We see RFID tags on bales as an important enabler to potential operational improvements and welcome a standard industry approach that promises to deliver benefits through the supply chain.*

Pettinatura Romagnano and Nejdek Wool Combing were excited with the idea of knowing exactly which bales were in each tri-pak/double, as well as the potential for being able to log their location when stored. Of equal importance is the ability to check bales as they enter the processing line to ensure the correct bales are being opened (e.g. prevent a coarse wool bale being opened into a fine wool consignment). Nejdek felt that they could work with a small number of tri-paks not reading until they were opened. The following are the post-trial responses from these companies:

Romagnano, Italy via Andrew Blanch (NEW Australia):

I had good feedback from Italy. Their only issue was how long until we can "go live"?? It would be a huge benefit to Romagnano.

Nejdek, Czech Republic via Louis Costin (Modiano UK):

I have spoken to the management here in London, who are all behind the technology. Another question they asked me is "when will it be implemented'?

5.2 Where to from Here?

AWEX has completed its RFID proving trials and is now working with its (Australian) e-Bale Implementation Working Group to ensure a consistent approach to the introduction of e-Bale to the industry. To provide economy of scale, it is important that the wool industry has a standardised approach to its use of RFID technology; and therefore to facilitate this, AWEX would welcome the opportunity to work with other wool producing countries and international wool customers. This collaboration could include consideration of preferred tags, other devices (fixed and hand-held readers etc.), as well as software (including WoolClip).

Note, it is envisaged that with the approval of the Australian wool industry, e-Bale would be adopted on an industry wide basis. The preferred tag would become part of AWEX's Wool Pack Standard. Thus, at a specific point in time, all the manufacturers of Australian wool packs would be encouraged to use pack labels that have an AWEX supplied RFID tag adhered to them.

6. ACKNOWLEDGEMENTS

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The author recognises the sustained support of the AWEX Board and management, which have backed the concept of e-Bale over many years. She also acknowledges the support and guidance of the e-Bale Technical Working Group comprising John Keniry (Chairman, AWEX), Mark Grave (AWEX), Andrew Blanch (New England Wool), Craig Finlay (AWH Ltd) and Charlie Merriman (WoolProducers), along with members of AWEX's Industry Services Advisory Committee (membership has changed over time).

With a view to progressing the adoption of e-Bale within Australia, an e-Bale Implementation Working Group has been formed comprising: John Keniry (Chairman, AWEX), Mark Grave and Kerry Hansford (AWEX), Ian Ashman (Australian Wool Testing Authority Ltd), Simon Hogan (Elders Ltd), Stephen Keys (Landmark), Marty Moses (Moses and Son), John Payne (AWH Ltd), John Roberts (Australian Wool Innovation) and Ed Story (WoolProducers Australia).

7. REFERENCES

Australian Wool Exchange Ltd (2015) *Wool Pack Labels,* http://www.awex.com.au/standards/wool-packs/wool-pack-labels/.

Australian Wool Exchange Ltd (2014) *WoolClip Electronic Classer's Specification Software Program,* http://www.awex.com.au/woolclasser/woolclip/.

Australian Wool Innovation (2015) *Australian Wool Production Forecast Report*, http://www.wool.com/market-intelligence/wool-production-forecasts/.

Creative Logistics Pty Ltd (2003) *Pilot Industrial Trial of Electronic Bale Identification.* Australian Wool Innovation Project EC-452, November 2003.

Hansford, KA (2007) *AWEX e-Bale Preliminary Trials: Outcomes and Conclusions,* Australian Wool Exchange Ltd Internal Report, November 2007.

Intrawool (2000) – *Wool Bale Identification – Evolution from Hand Stencil to Transponder,* European - Australian Co-operation Project, Bremen Institute for Production and Logistics GmbH, February 2000.

Karmaker, N (2013) *Desktop Review on State of the Art RFID Technology for Australian Wool Industries*, Australian Wool Exchange Ltd Internal Report, March 2013.

Schmitt, L (2006) *AWEX E-Bale Project – Technology and cost/benefit assessment of electronic bale ID*, Australian Wool Innovation Project TD-043, January 2006.

Swain, BC (2006) *AWEX e-Bale Preliminary Trials: Outcomes and Conclusions,* Australian Wool Exchange Ltd Internal Report, June 2006.

Wilcox, C (2014) *Cost-Benefit Analysis of Radio Frequency Identification (RFID),* Poimena Analysis Report to Australian Wool Exchange Ltd, June 2014.

Wolhers, AC (2015) *RFID X-Bred Analysis*, Report to AWEX by Statistical Investigations Pty Ltd, Elsternwick, Victoria, June 2015.

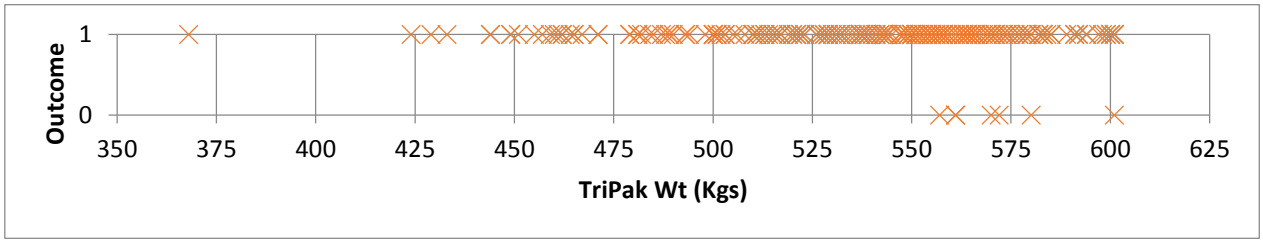
Young, SSY (1955) *A survey of moisture content in some greasy wool from New South Wales*, Australian Journal of Agricultural Research, Volume 6, Issue 4, p. 624 – 639.

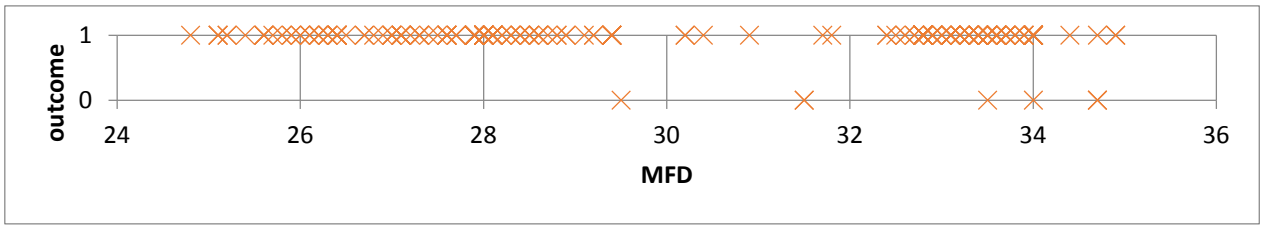
8. APPENDICES

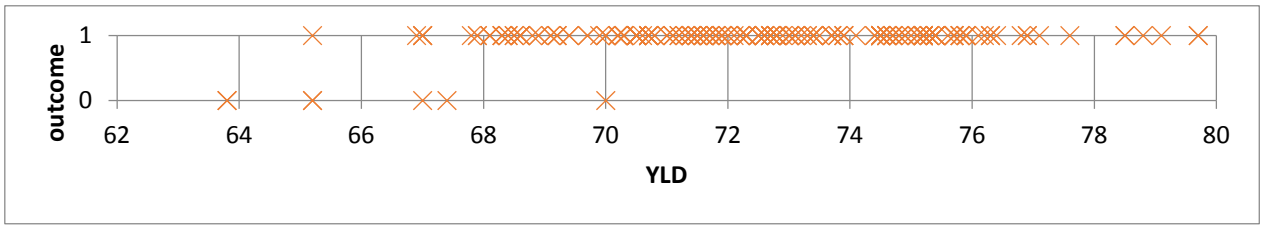
Appendix 1

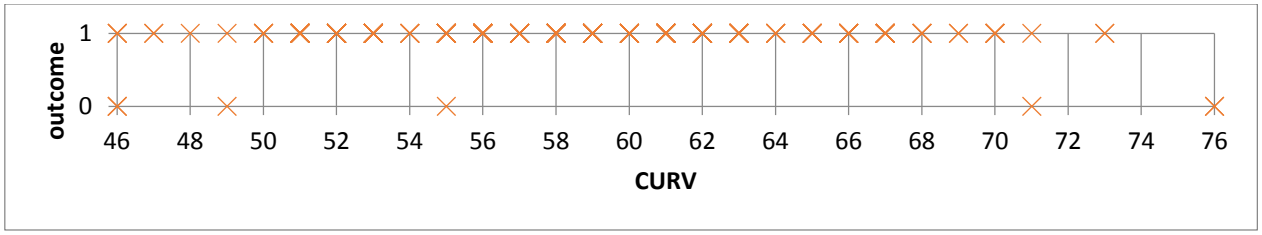
Graph 1 shows a binary outcome (0 = 'No RFID' vs 1 = '1 or more RFID') plotted against each predictor variable.

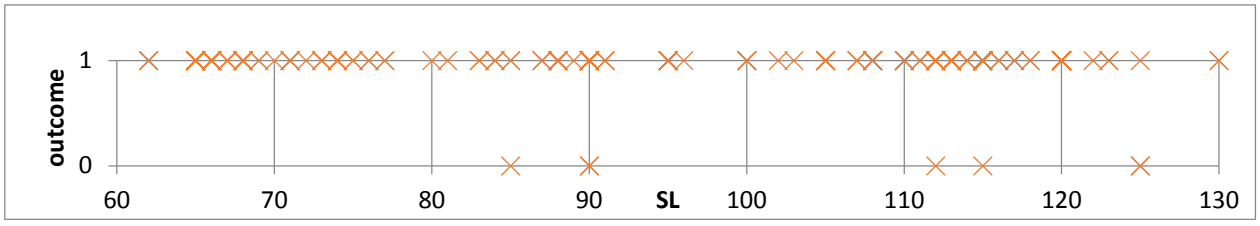
Graph 1: Reads (1, 2 or 3) c.f. No Reads for Tri-pak Wt, MFD, YLD, Curv, SL & VMB

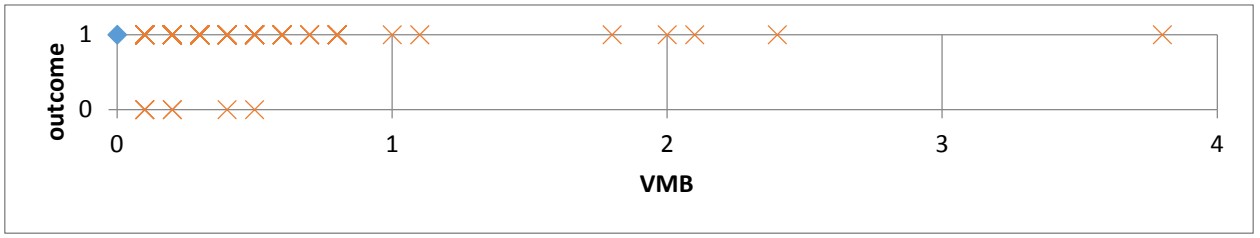












These plots show that with the exception of YLD, the Outcome = 1 and Outcome = 0 distributions of the predictors overlap. This means we would not expect them to be important predictors in a model of Outcome as a function of predictors.