Final report

Quantifying the opportunities for beef industry automation and productivity value proposition to stakeholders

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Executive Summary

After the successful development of the LEAP series of fully automated boning room systems, MLA is now focussing on a similar development path for beef boning automation.

Various previous studies have been made by MLA as regards the potential design and net benefits of beef boning automation. However, the modelling in this report is based on the latest beef boning design approaches, includes previous CBA work where applicable, and summarises the potential benefits of both stand alone and integrated beef boning systems.

The two key modules are the following.

Module 1 – Beef Scribing System (page 39)

- Chuck Rib Scribing ($0.23 to $0.44/hd)
- Back Rib Scribing ($0.49 to $1.73/hd)
- Chuck to Cube roll separation ($5.25 to $6.13/hd)
- Striploin & Rump separation ($0.16 to $0.17/hd)

The benefit of this system could be further increase by the inclusion of the Striploin to Cube roll cut. The benefit of this has not been included as it is currently completed manually so that grading can occur.

Module 2 – Beef Chining System (page 41)

- Chining of the Cube Roll ($4.63/hd)
- Chining of the Striploin ($3.80/hd)
- Button bone removal

Aitch bone and knuckle removal has not been included in the modelling, as these tasks cannot be fully automated at this time. However, the semi-automated SAR beef puller is commercially available, and adding these units would provide further estimated benefits of $3.44/hd to the boning room.

Table 1 shows the financial benefit for the beef scribing & chining modules as part of the Single Rail integrated system. Using the benefits for yield, labour, OH&S the expected payback period for the beef scribing system is between 1.61 and 1.96 and the chining system is expected to have a 2.10 years payback. These payback periods have been calculated for a medium size beef plant in Australia.

Table 1: Financial summary for the development of the Single Rail and Module 1 & 2.

SUMMARY PERFORMANCE MEASURES						
	Single rail		Beef scribing		Chining	
Hd / annum	328,320		328,320		328,320	
Production increase with equipment	8.20%		3.13%		3.13%	
	Avg.	To	Avg.	To	Avg.	To
Capital cost (pmt option, upfront)	$11,649,500		$4,699,500		$6,200,000	
Gross return Per head	$17.17	$18.78	$7.57	$9.18	$9.22	$9.22
Total costs Per head	$4.06		$1.69		$2.13	
Net Benefit Per head	$13.11	$14.72	$5.88	$7.49	$7.09	$7.09
Annual Net Benefit for the plant	$ 4,304,063	$ 4,832,108	$ 1,929,531	$ 2,457,576	$ 2,326,672	$ 2,326,672
Annual Net Benefit for the ex cap	$ 5,469,013	$ 5,997,058	$ 2,399,481	$ 2,927,526	$ 2,946,672	$ 2,946,672
Pay back (years)	2.13	1.94	1.96	1.61	2.10	2.10
Net Present Value of investment	$31,889,801	$35,967,222	$14,483,580	$18,561,001	$17,171,162	$17,171,162

minute.

Table 2 presents the financial opportunity to be gained through investing in a complete beef automation system, which is the integration of the Beef Scribing and Chining systems above.

The single rail system will be developed for small to medium plants whereas the dual rail system is for larger higher throughput plant. The payback is estimated at 1.46 to 1.60 year for a large plant and 1.94 to 2.13 for a small plant. The total capital costs for the dual rail system is much higher than the single rail system so as to enable the high throughput of the system per minute.

Table 2: Financial benefits of the Dual & Single rail automation systems

SUMMARY PERFORMANCE MEASURES				
	Dual Rail		Single rail	
Hd / annum	656,640		328,320	
Production increase with equipment	9.89%		8.20%	
	Avg.	To	Avg.	To
Total Capital cost (pmt option, upfront)	$17,471,700		$11,649,500	
Capital Cost of Main Componants				
Beef Scriber	$8,971,700		$3,399,500	
Chining	$4,000,000		$4,000,000	
Imagry Costs				
DEXA	$500,000		$500,000	
CT	$1,500,000		$1,500,000	
Other Installation Costs				
Essential and insurance spares	$500,000		$500,000	
Integration	$1,000,000		$750,000	
Other Capital install	$1,000,000		$1,000,000	
Gross return Per head	$16.88	$18.48	$17.17	$18.78
Total costs Per head	$2.93		$4.06	
Net Benefit Per head	$13.95	$15.55	$13.11	$14.72
Annual Net Benefit for the plant	$9,158,123	$10,211,209	$4,304,063	$4,832,108
Annual Net Benefit for the ex cap	$10,905,293	$11,958,379	$5,469,013	$5,997,058
Pay back (years)	1.60	1.46	2.13	1.94
Net Present Value of investment	$68,103,292	$76,234,939	$31,889,801	$35,967,222

The above is based on the latest information available from MLA and SAR, but it should be recognised that at this early stage of development, some costs are estimated only and will change.

Furthermore, there are some cuts and tasks that may offer further benefits, but have not been included in the current system design. These have been highlighted in the report for further consideration.

The three horizons strategy proposed by Greenleaf Enterprises can act as a macro-level blueprint in guiding industry towards beef automation, but the industry should be in no way limited to only these recommendations. The pace of innovation in manufacturing around the world, and the development of AI and machine learning technology have the potential to further revolutionise red meat processing and address some of the tasks that are currently not feasible with existing technologies.

Glossary

Term	Description
Caudal	Caudally: toward the posterior end of the body
CBA	Cost Benefit Analysis
Cranial	Refers to the direction toward the head of carcass
Dorsal	Belonging to or on or near the back or upper surface of an animal
Ex-ante	"*Before the event*". Ex-ante is used to describe scenarios where results of a particular action, or series of actions, are forecast (or intended) in advance.
Ex-post	The opposite of ex-ante is ex-post (actual)
HSCW	Hot Standard Carcase Weight
MLA	Meat & Livestock Australia
OH & S	Occupational health & Safety
SAR	Scott Automation & Robotics (previously Scott Technology)
Statistical hypothesis test	A method of making decisions using data, whether from a controlled experiment or an observational study (not controlled). In statistics, a result is called statistically significant if it is unlikely to have occurred by chance alone, according to a pre-determined threshold probability, the significance level. The phrase "test of significance" was coined by Ronald Fisher: "Critical tests of this kind may be called tests of significance, and when such tests are available we may discover whether a second sample is or is not significantly different from the first."[1]
Ventral	Pertaining to the front or anterior of any structure. The ventral surfaces of the carcass include the brisket /abdomen cavity

1 Contents

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2 Introduction

MLA has successfully developed lamb processing sensing and automation technologies in collaboration with commercialisers and industry partners. These technologies have delivered significant productivity benefits from yield and throughput increases, as well as some labour savings. This value proposition has fuelled in part industry awareness to, and acceptance of, investment in automation that is resulting in continued adoption. Digital data collection and analysis from automation systems are also providing objective measures for improved decision making along the entire chain and are beginning to enable whole of chain transformations.

Beef processing is more difficult to automate than the lamb industry for many reasons. Although some beef automation with integrated DEXA scanning has been successfully installed (beef rib cutter), beef boning room automation systems are yet to be explored properly. Given the significantly greater size and value of beef carcases relative to lamb, the opportunities and potential value from these investments is significant.

3 Background

3.1 Beef Automation Currently Available

Scott Automation & Robotics (SAR) and MLA have been collaborating since early 2002 to automate the bone-in cutting process of the lamb sector. Although still undergoing R&D in some areas, commercial equipment is being realised with Australia's first automated x-ray lamb boning module installed and commercially operated by ALC since December 2011. The successful ALC installation has resulted in ALC proceeding to install the next automated x- ray lamb deboning module, as well as JBS installing both the existing ALC system and the new module.

Aside from fit for purpose engineering provided by SAR, one of the most significant enablers has been the use of a continuous lamb full carcase x-ray system that provides the required bone cutting locations for the automated system.

Current beef automation technologies from SAR

- **Beef Rib Cutter/Scriber**: aims to replace manual scribers or rib cutter operations through a robotic arm integrated with a scribing saw and sensing technology. The sensing technology combines x-ray (DEXA), 3D scanners, colour camera and robotics to accurately determines the optimum cutting lines. While the robotic arm makes the incisions in order to maximise yield benefits (SAR 2018).
- **Beef Boning Unit:** is a mechanical assisted arm that enables manual workers to bone the aitch bone and knuckles with minimal effort (SAR 2018).
- **Beef Hock Cutter:** is a robotic solution that replaces the manual hock cutting operation. The robot is integrated with sensing technology to detect and cut the hock with high accuracy (SAR 2018).
- **DEXA Beef Carcase Composition Grading:** provides an objective measurement of beef side composition. The information is used to determine the lean, fat and bone composition of

each carcase, and allows the optimisation of the cutting specifications for each carcase. This allows a more accurate pricing decision based on increased yields gained from sides (SAR 2018).

4 Objectives

The objectives of this project are as follows:

- Consolidate previous value-propositions into one industry benefit analysis
- Undertake validation work with 2 to 3 strategic processors and appropriate automation suppliers
- Consider factors that have impacted both positively and negatively on lamb industry automation development and adoption to inform return on investment assessment frameworks for future beef industry automation.
- Identify new value opportunities and prioritize development ROI based on likely development success and likely adoption
- Consider behavioural economic factors influencing future beef industry automation development and adoption
- Develop fact-based assumptions on the rate of adoption of beef automation based on ex-ante value propositions

In doing so, the following activities will be undertaken:

- Revised data collection and modelling for whole of beef industry benefit
- Develop a consultation process with key stakeholders that allows data collection and discussion with active supply chain members across all sectors.

5 Methodology

5.1 Industry Review

A framework was developed to address the industry review objectives to structure and guide site visit investigations. The list of activities completed during discussions with industry participants and the cost benefit analysis are below:

- Identify specific capabilities of beef automation that were different to manual processes and other existing technologies.
- Clarify how these capabilities deliver value.
- Apply this value to wider industry benefit including likely impact on adoption.
- Determine the current limitations of proceeding forward with automation technologies and the cost of addressing these technologies.
- Assess the significance of beef automation capability to the industry now and in the future considering other known technology development pathways with similar industry benefits.
- Determine the risk for industry challenges of not proceeding with beef automation.

Site visits were conducted, along with discussion and input from industry participants to test and validate the findings reported.

5.2 Desktop Study

Seven previous reports from Greenleaf Enterprises on both lamb and beef automation technology were reviewed to synthesise the lessons learned from lamb automation and how they transferred and correlate to beef automation (Table 3). These reports include:

Table 3: Previous reports from Greenleaf Enterprises

Report Name	Type of Machine	Cuts affected
Ex-Post Cost Benefit Analysis of automated x-ray beef rib cutter	DEXA for image analysis, robotic arm, scribing saw attachment	Beef scribing
Hook-Assist CBA and feasibility for future modifications	Cobotics Intelligent Assist Devices (IADS)	Support operators in physically challenging tasks. Rib scribing, Navel Brisket, Clod, Cube Roll, Aitchbone, Knuckle.
Feasibility Review – Automated x-ray Beef Boning Solution	Fully automated x-ray beef boning solution	Splitting of the forequarter between the 5th and 6th ribs; Scribing of the ribs through the point end forequarter; Dissection of the navel end forequarter; Splitting of the hindquarter between the rump and striploin; Refining the hindquarter boning process;
Lamb middle cutting system, Ex-Post Review	Saddle/Middle Processing System. An automated lamb middle cutting system guided with the use of camera visioning and integration with an existing x-ray primal cutting system.	Rack/loin separation Flap removal Spinal cord removal Splitting of rack and/or loin Chine bone removal
Operated Assisted Beef Loin De-Boning Saw	SAR aimed to remove the operator away from a bandsaw by automating the sensing and 'driving' of the meat primal (the loin) through the bandsaw on a newly developed moving table.	Chain Boning, Table Boning, SAR's Loin Saw, Generic Loin Saw
Value Proposition for automated beef scribing	Automated beef scribing process	Beef Scribing
Robotic Beef Hock/Hoof Cutter, ex-post review	Robotic Beef Hock/Hoof Cutter	This system identifies the ideal location on the front legs to remove the hock, stabilises the carcases and removes the fore hocks.

5.3 Yield data collection method

This section describes the methodology used to collect data and establish measurement standards that underpin the costings and value proposition in section 7. The methodology describes the data collection for the following areas:

- Yield loss due to variation in cuts;
- Labour savings;
- OH & S savings;
- Upkeep and consumables used by the current and proposed systems;

The cut lines shown in Figure 1 were included in this ex-ante study except for cuts 2 and 10. Cut 10 is not currently conducted in the plant and cut 2 was removed from the data set as this cut is currently conducted in the chiller to allow for MSA grading prior to the carcase entering the boning room.

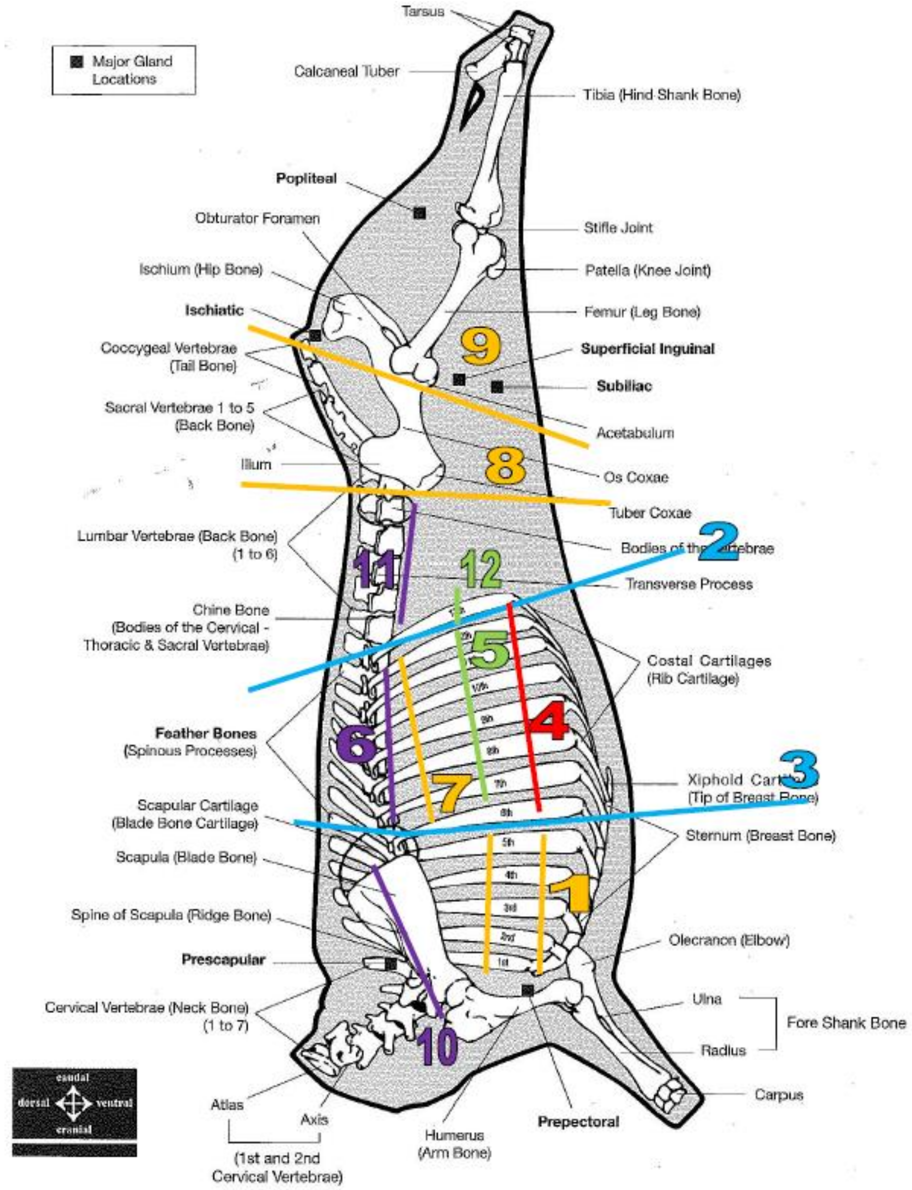


Figure 1: Cutting lines included

5.3.1 Forequarter

5.3.1.1 Horizontal cut between 5th & 6th Ribs (Cut 3)

The green line in Figure 2 illustrates the ideal location for cut 3, which is currently conducted manually. This requires the operator to split the vertebrae and then twist the carcase to get as close to the cranial edge of the 5th rib as possible. The curved nature of this cut is required to ensure maximum yield of the cube roll, navel end brisket, short ribs, back rib bits and back ribs.

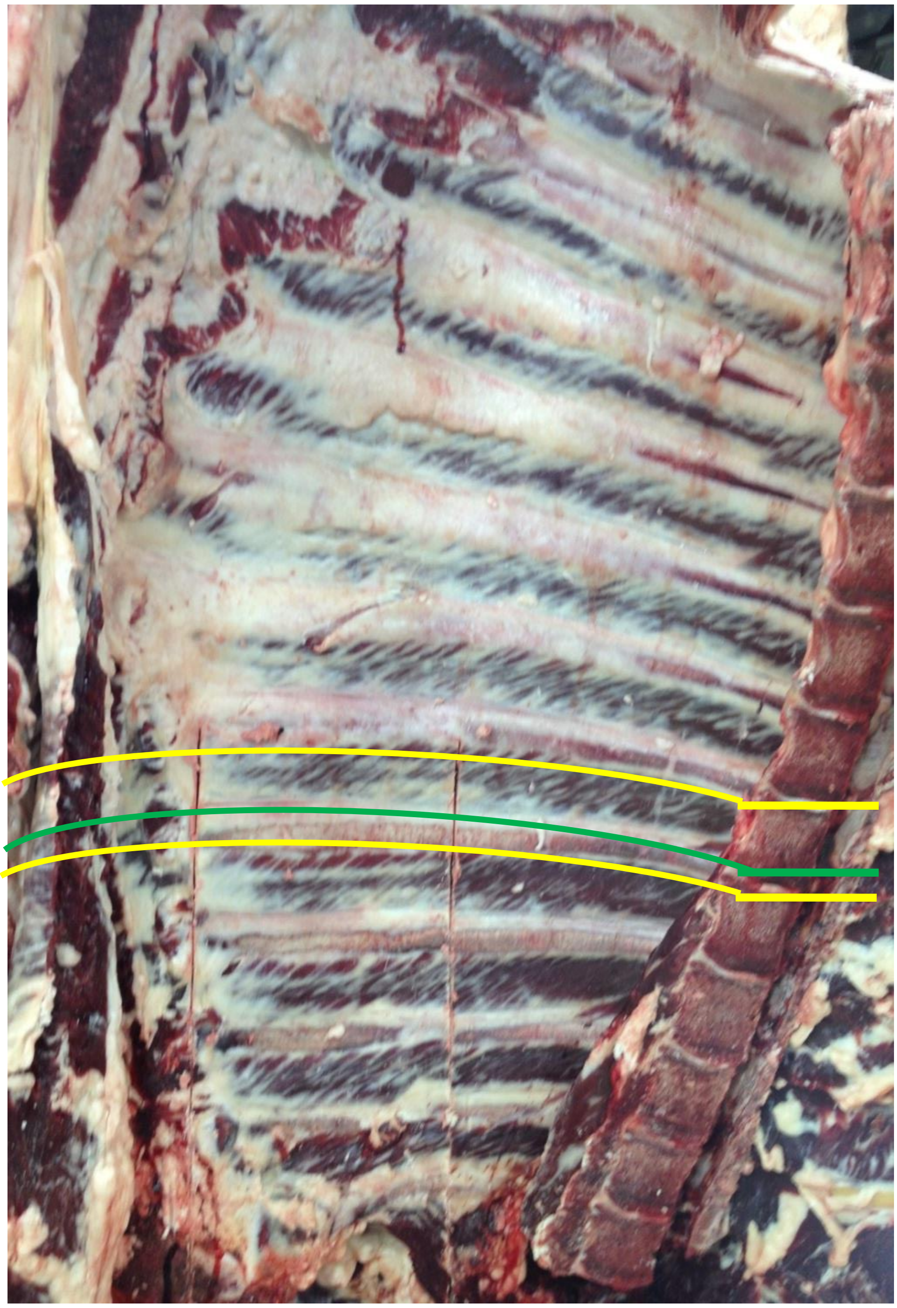


Figure 2: Location of the ideal splitting between the ribs 5 & 6. The yellow lines represent the variation observed from the ideal line shown in green

The variation observed in cut 3 is shown in Figure 2 by the yellow lines; the ideal location for this cut is shown by the green line. The standards for this cut were developed to establish the loss of yield from the cube roll, short ribs, back ribs, and the back rib bits. The development of the standards can be seen in Figure 3.

The variation observed in this cut was higher in grass fed than grain fed carcases with 25% having a section of the 6th rib included in the point end forequarter.

Figure 3: Setting the 10mm standard for variation in cut 3.

The amount of variation occurring in this cut would be increased if the cut wasn't being conducted by a very skilled operator who understands the importance of rotating the carcase. It was flagged that when the current operator is on a rostered day off or leave the variation in cut increased dramatically.

The installation of the x-ray beef solution will add value to this cut by increasing the accuracy of the cut placed along the edge of the 5th rib. The robot will identify the edge of the 5th rib and guide the blade to precisely cut along the edge of the rib. This will decrease the chance of bone fragments ending up in trim by conducting this cut using an automated knife. This will cause all the intercostal to remain on the caudal side of the cut (attached to the 6th rib). Thus maximising the weight of intercostal sold as short ribs, back ribs and back rib bits.

5.3.1.2 Scribing Point End Brisket (Cut 1)

Cut 1 is conducted by a twin bladed saw to cut the depth of the ribs so the chuck ribs can be removed. The ideal spot for this is shown by the yellow line in Figure 4 and Figure 5, which is the knuckle between the breast bone and the 2nd rib. This ensures the chuck short ribs can be removed from the chuck forequarter along the chain.

The target location of the manual cut has been identified by the plant to account for operator variation in the scribe across the ribs. During the development of the standards it was identified that with an increase in accuracy, a robot can allow for the ideal location of this cut to be moved to 5mm past the joint towards the breastbone. The proposed changes to these cuts have been shown by the white dotted line in Figure 4.

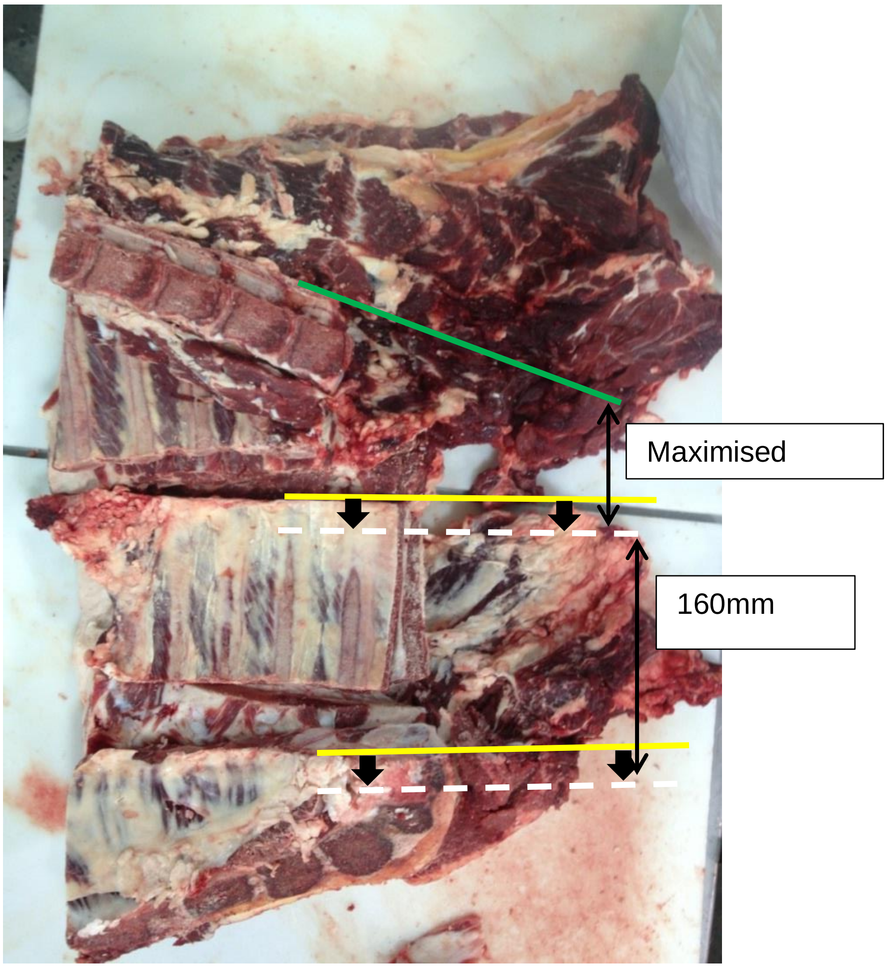


Figure 4: Current and proposed cuts for the point end forequarter

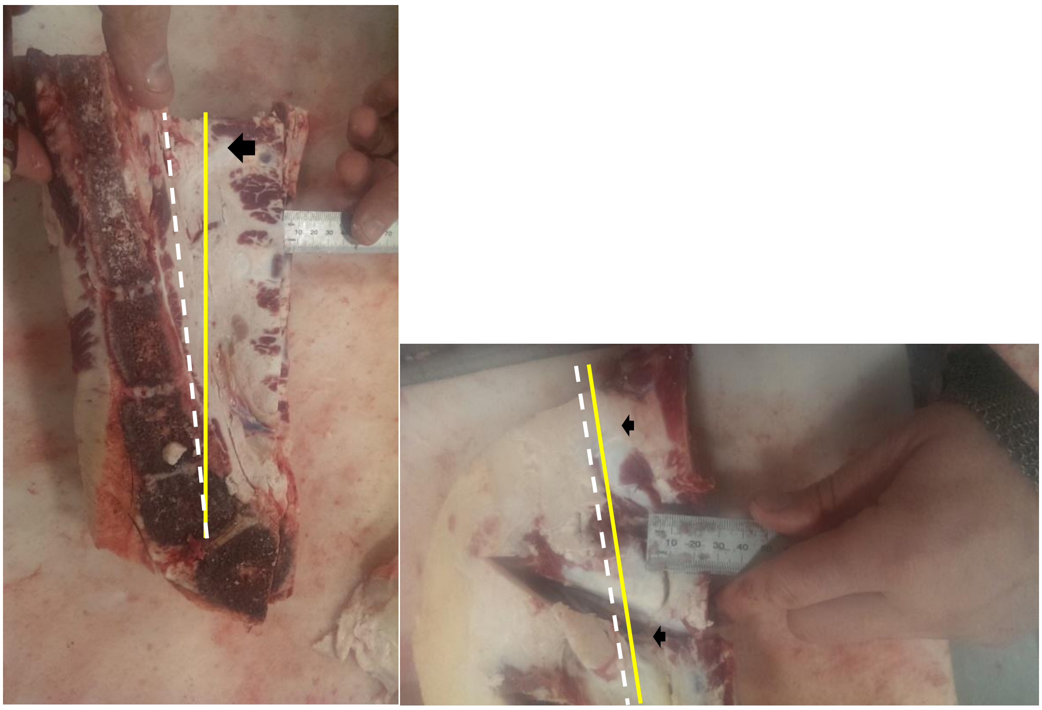


Figure 5: Variation in current and proposed cuts on the Breastbone

The variation in the ideal location of the scribes will have a positive effect on the amount of bone sold as chuck ribs, increase the number of intercostals over 150mm in length (which achieves a higher price/kg) and increase the weight of the chuck flap tail.

The standards were developed to predict the increased length and weight of the intercostal. The process involved with setting the standards for the intercostals were:

1. Weigh the intercostal and bone;
2. Take a 10mm strip off the end of the bone to calculate the weight associated with the increase in length;
3. Bone out the intercostals and measure their length;
4. Measure the length between the end of the rib and the vertebrae;

Figure 6: Length of intercostal between ribs 1 and 5

By optimising the placement of cut 1 across the width of the shoulder with the X-ray visioning there is an opportunity to maximise the length of the intercostal (increased value) without compromising the other shoulder cuts value.

Through moving the cuts in the ventral direction it has allowed for an increase in the amount of product sold as intercostal. The yellow line in Figure 6 represents the variation in the lengths of saleable intercostal above or below 150mm. As can be seen by the three intercostals below the ruler, 1 may fit into the over 150mm specification but the other two will not. If the cuts are moved as proposed in Figure 4 then there will be two additional intercostal sold at the greater value per kg.

This scribe line sets the location of the dissection of the chuck flap tail, point end brisket and trim. Once the chuck ribs have been removed from the point end of the carcase the boner removes the brisket. As can be seen in Figure 7 as the chuck ribs are moved in a ventral direction on the carcase the meat available for the chuck flap tail increases. The blue line to the right of the image below moves towards the chuck ribs increasing the weight of the chuck flap tail.

Figure 7: Increasing length of Chuck flap tail from point end brisket.

5.3.1.3 Vertical cuts across the 6th to 13th ribs (Cuts 4, 5, 6 & 7)

The current procedure used to split the navel end forequarter into 3 sections and remove the chine is conducted in the following order (cuts are shown in Figure 8):

1. Cut 4, (brisket scribe line) to remove the navel end brisket;
2. Cut 5, to remove the short ribs;
3. Cut 6, which removes the chine;
4. Cut 7, which is removes the back rib bits from the back ribs

The manual accuracy of these cuts is relatively high as cut 7 is guided by a laser line across the navel which sets the location of cuts 5 and 7. The method does create variation in the width of the short ribs depending on the size of the animals being processed. This can affect the width of the short ribs as a result of the size of the carcases. The proposed x-ray solution could start cuts based on the size of carcase and maximum allowable size of all the higher value cuts, rather than a fixed anatomical location on the navel. Optimising the location of cut 7 cutting line at the cube roll rather than starting at the lower value navel end brisket could maximise the saleable value of this section of the forequarter.

The current process involved with these cuts requires 4 bandsaws operators. One of these operators controls the speed at which the chain can feed forequarters into lines 1 and 2 of the boning room. Cut 5 and 6 currently requires 2 bandsaws at the start of line 2 which have to maintain a high throughput to keep up with the flow of product. The fourth bandsaw is located at the end of the boning room which removes the back rib bits from the back ribs. This bandsaw will remain after the x-ray system is installed although a guide will be fitted to reduce the variation of this cut.

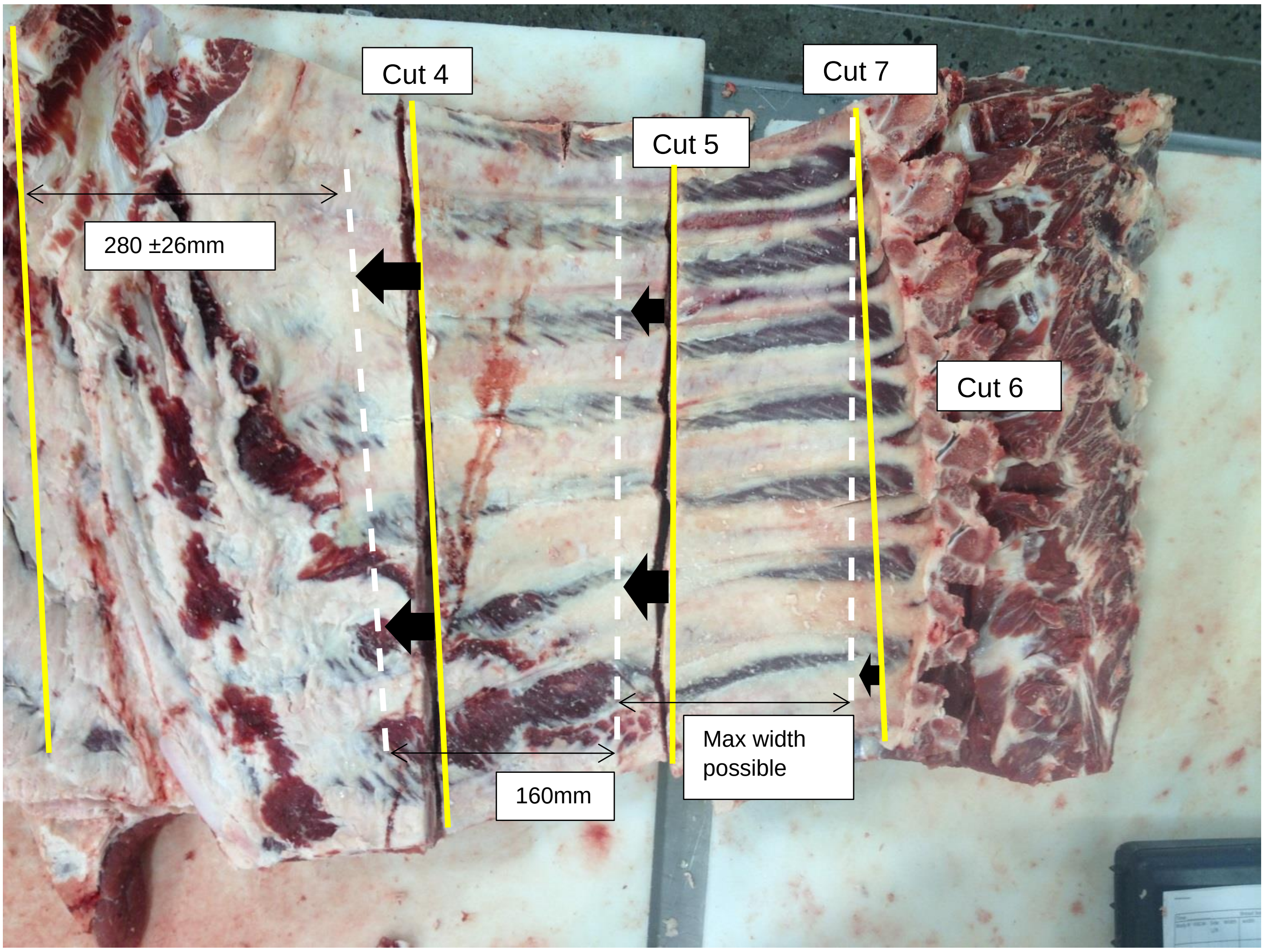


Figure 8: Navel end forequarter cuts - current and proposed

Automation system considerations

To maximise the width of the back ribs the order of the cutting lines need to be modified. The proposed method of adjusting the cutting lines in Figure 8 with the installation of the robotic system is as follows:

1. Cut 5 - Remove the short ribs from the back ribs,
    a. This cut will be all the way through the ribs to split the navel end of the forequarter in two.
2. Cut 4 - The brisket scribe line,
    a. The robotic system needs to cut all the way through the ribs
3. Cut 6 - Removal of the chine,
    a. This is to be conducted on a bandsaw with a chine guide fitted.
4. Cut 7 - Removal of the back rib bits from the back ribs,
    a. This will be completed by an operator using a bandsaw with a guide fitted.

The above process will maximise the saleable weight of back ribs by moving the cutting lines to the white lines on Figure 8.

Saleable Ribs

There is an opportunity to increase the weight of the following higher value cuts. The value proposed for each cut will be explained separately but each cut will affect adjoining cuts.

Figure 9: Ventral end of the Navel end brisket with the intercostal removed

Moving cut 4 towards the breastbone (Figure 9) will increase the bone and meat sold as back ribs and decrease the products sold as intercostal and render. The standard to estimate the effect of variation in the length and weight of the intercostal was established by boning out the breastbone as shown in Figure 9. The weight to length ratio of the intercostal with a 10mm strip removed developed the standard.

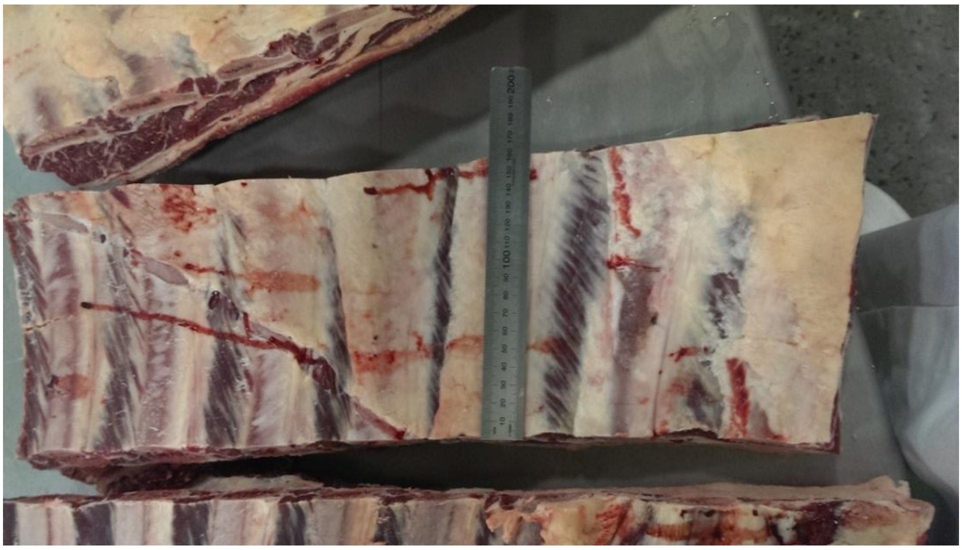


Figure 10: Short Ribs

There will be limited value added to the short ribs as they are currently cut using a guide on the bandsaw.

Figure 11: Back rib width can be maximised with the robotic system

The back ribs are currently the last section of the ribs to be cut when the back ribs bits are removed. Most of the value added to this section will be to maximise the width of the back ribs by calculating the required length of all sections of the rib cage.

The location of cut 4 affects the width of the navel end brisket. The ideal location of cuts 4, 5, 6 and 7 all affect the width of the back ribs which are to be maximised. The system will increase the amount of bone sold as back ribs by calculating the ideal locations of these cuts for each carcase, thus maximising the saleable product on every carcase. For this calculation to work successfully the Linea Alba (white fibrous tissue) or similar structures on the ventral end of the carcase would need to be identified by the x-ray solution.

Effect on Saleable Meat Products

There are currently two options available for the development of the cutting system through the x-ray beef solution. They are as follows:

<u>Scribing the ribs only the depth of the bone</u> - The cuts removed from the navel end brisket shown in Figure 12 will be maximised using a scribe cutting saw to only cut the depth of the bone. This will allow for the navel end brisket and subway meat to be separated as required by the slicers and reduce the product sent to trim.

<u>Cutting the ribs using a circular saw</u> - The other option for this cut is to slice the forequarter completely through with a circular saw. This would reduce the weight required to be lifted by a slicer after the cuts have entered the boning room belt. The main concerns in conducting this cut with a circular saw is the white dotted line in Figure 12 (cut 4) may protrude into the Navel half. An anatomical structure will need to be identified which can be identified by the x-ray to ensure the cut is always conducted on the edge of the Navel half.

The standards to estimate the effect of value between the subway meat and the trim were as follows:

1. Bone the ribs off the carcase and trim the short ribs. To ensure there was no weight lost off the short ribs by moving the cut in a Ventral direction.
2. Measure and weigh the weight of the trim shown in Figure 12.
3. Take a 10mm strip off the subway meat to calculate the weight of muscle when moving the cut in a ventral direction.

These measurements were then used to calculate the value gain or loss as a result from moving this cut.

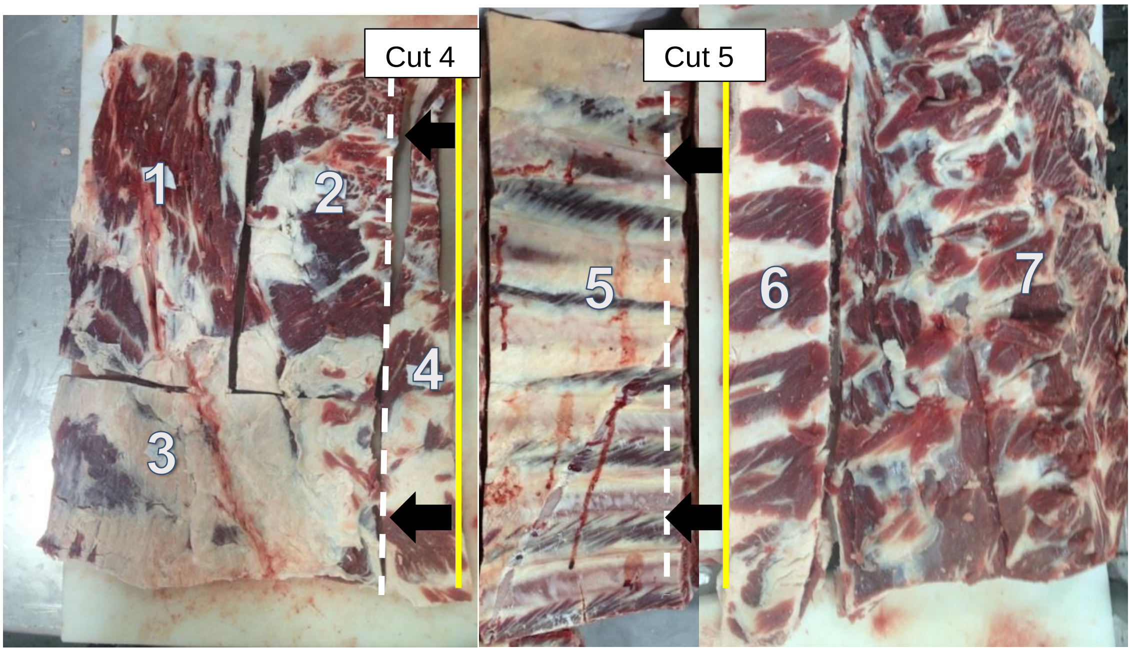


Figure 12: Cuts removed from the navel end brisket, 1) Kalbi Plate, 2) Navel half, 3) Rib end meat, 4) 65Cl trim, 5) short ribs (prior to trimming), 6) Subway meat, 7) Cube roll

5.3.2 Hindquarter

The two cuts through the hindquarter are currently conducted on 3 bandsaws with 2 table bandsaw required on Cut 8 to maintain line speed while 1 in-line saw conducts cut 9. The proposed x-ray system will conduct cut 8 on 1 saw and replace both bandsaw operators. An alternative boning method using an aitch bone puller is expected to give better boning yields and would replace the saw operator on cut 9.

5.3.2.1 Cut 8

The ideal location for cut 8 is across the face of the rump and the sirloin, thus if the saw is inaccurate muscle will be lost from either the striploin or the rump cap. Cut 8 is completed by the first operator which has to manoeuvre the shortloin into the correct position which in some cases involves leaning across the saw blade. The biggest challenge is making a square cut as the shortloin does not lie flat on the bandsaw table.

The main benefit of the x-ray solution is the increase in accuracy, reducing the yield lost from the striploin or rump. There will still need to be the same boners on the chain prior to the cuts being performed to ensure that the tip of the tri-tip is not cut off during the cutting process.

Cranial Direction

The method used to accurately gauge the loss of product from the striploin was conducted by measuring the amount of muscle left on the bone. The meat left on the bone in Figure 15 was collected off the bone belt. The number of cuts inaccurate in the Caudal direction tended to increase after lunch where the chain was travelling faster giving the saw operator less time to conduct the same job.

Figure 13: Striploin loss to render from an inaccurate cut

Figure 14: Standards where the cut removes a section of the rump cap

Caudal Direction (Rump Cap Left on the Bone)

The method for gauging the accuracy of cut 8 in a negative direction (cut into the aitch bone) involved identifying the amount of bone and muscle removed from the end of the aitch bone. The measures used for -3, -5, -8 and -10mm can be seen in Figure 14. The effect of the cut being conducted in a negative direction cause the end of the rump cap to be sold as trim.

Angulation of Cut 8

The variation in the angle of cut 8 was collected by measuring the distance cut over or under the ideal line on both ends of the striploin identified by the 1 and 2 shown on Figure 15. Measurement 1 was taken as shown in Figure 13 and measurement 2 was taken as the distance from caudal end of the 5th lumbar vertebrae.

Figure 15: Striploin yield lost due to an inaccurate cut

The variation in angle between the samples taken seemed to vary substantially (Figure 15) when the two recordings were compared together. It appears there is as much variation in the angle as in the movement into the striploin.

Cut angle tended to vary depending on the rate at which the chain was running. The operator of the bandsaw conducting this cut is required to do the same amount of work irrespective of the chain running at 130 or 150 bodies per hour. The operator of the bandsaw is doing a good job with more than 30% of the cuts in the ideal location.

5.3.2.2 Aitch Bone (Cut 9) & knuckle removal

The benefit for the aitch-bone and knuckle removal has been excluded from this project as these benefits can been obtained via installation of the commercially available SAR beef puller system.

Aitch bone and knuckle removal options are further discussed under Section 11.4.7.

5.3.3 Loin Deboning (Cuts 6 & 11)

5.3.3.1 Production sampling versus statistically robust yields

Most processing plants have internal reporting methods used to monitor primal cut yields as a percentage of carcase weight. This reconciliation of carcase weight into the boning room against weight of primals packed is an effective method when monitoring boning room yield over a day or a run of carcases. Assuming the loin saw delivers an improvement in yield over table or chain boning, you would expect the finished vacuum packed primals to be heavier than those processed using the lower yielding manual methods.

Given the variation in carcase weight, fat cover and carcase muscling, a very large number of carcase would need to be sampled to demonstrate this. Conducting comparative trials using left and right sides of the same carcase does minimise variation. However, a number of factors present variations in results that are greater than the variation in yield between table boning, chain boning and removal of the chine bone by SAR's saw. These sources of variation are summarised in Figure 16 and the methods used to run the trials and collect data are included in the methodology section below.

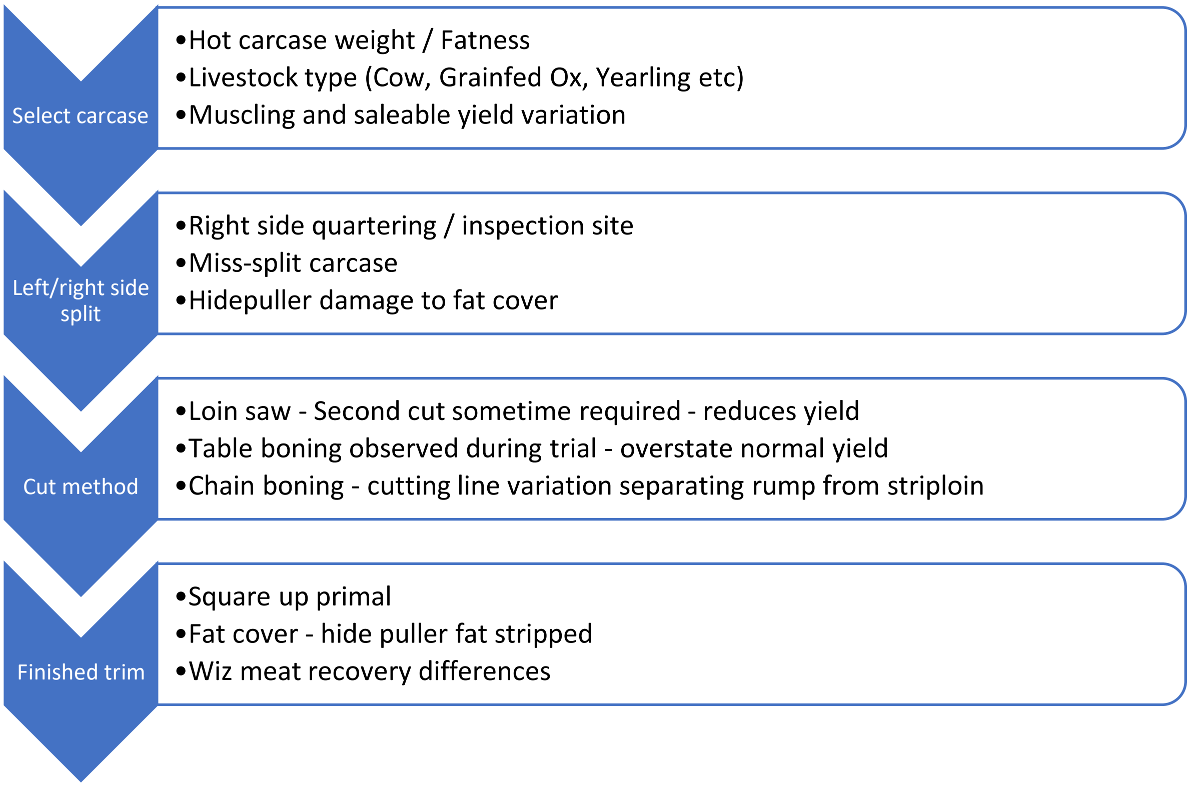


Figure 16: Sources of variation between samples requiring a different measurement methodology

5.3.3.2 Trial Methodology

1. Select carcase on chain
    a. Left and right side details recorded from carcase ticket
    b. Each side of the carcase followed through the boning process to the point of loin removal
    c. At the point of boning striploins the flank has been removed from the quartered side
2. Boning Striploin
    a. Chain boned (One side)
        i. Rump separated from aitch bone, continuing down into striploin separation from the vertebrae leaving the rump attached to the striploin.
        ii. Continue to separate striploin from the vertebrae removing fully intact boneless rump and striploin from the carcase
        iii. Striploin separated from the rump with a knife cut on the boning table
        iv. Boned vertebrae removed from the carcase making a knife cut between the vertebrae
        v. Wiz knife removes remaining trim off vertebra and saved for weighing
    b. Table bone
        i. Bone in striploin removed by cutting through the vertebrae between the striploin and rump
        ii. Bone-in weight recorded
        iii. Bone-in striploin boned out on table off-line by the same boner and trimmed by same slicer
        iv. Wiz knife removes remaining trim off vertebra and saved for weighing
    c. Saw de-boning
        i. Bone in striploin removed by cutting through the vertebrae between the striploin and rump
        ii. Bone-in weight recorded
        iii. Vertebra removed on loin saw by the operator on duty that day
        iv. Both loin and vertebra saved for weighing
        v. Wiz knife removes remaining trim off vertebra and saved for weighing
    d. Vertebra, rib, wiz trim, other bone, fat and finished striploin collected for further trimming and weighing
3. Weighing and recording results, start the process again

5.3.3.3 Table boning

Figure 17: Bone-in loin prior to table boning

Figure 18: Loin bone after table boning plus wiz trim

5.3.3.4 Loin saw boning

Figure 19: Bone-in loin after removing backbone with saw

Figure 20: button bones are removed from striploin with a wizard knife after saw cut

Figure 21: Ribs and vertebrae need to be separated for boning otherwise a second saw cut is required to enable boning

Figure 22: Measurement process to capture weight of bones relative to primal, wiz trim and fat weights

5.3.3.5 Chain boning

Chain boning can be done by removing the bone from the hanging muscles as in Figure 23 and Figure 24. Alternatively, the rump and striploin can be removed from the skeleton as done during the trials at the plant. In both options the separation of rump from striploin occurs after removing the muscles from the carcase. This cutting line between rump and striploin can be done in a slightly different place than removal of bone-in striploin for table boning or loin saw boning. This is an additional source of variation when comparing finished primal weights as a percentage of total carcase weight.

Figure 23: Chain boning removing the bone from the hanging muscle

Figure 24: Cutting line to separate rump and striploin after boning

Figure 25: Removal of bone-in striploin ready for table boning

Figure 26: Chain boned striploin and removal of vertebra from carcase for weighing post boning

5.3.3.6 Finished Specification

All primals were trimmed to packed specification. This included squaring up ends as required, measuring and cutting the same tail length for each primal and trimming fat cover back to correct depth.

Figure 27: Trimming boneless striploin primal to finished specification

5.3.3.7 Generic saw cutting line versus SAR's loin saw

Figure 28: Cut is very close to hands and requires cut to be curved following orange arrow on picture to remove vertebrae with highest yield

Figure 29:Steel mallet used to force the separation of ribs from vertebra where cut leaves ribs joined

Figure 30: Safety benefits of removing hands from cutting area

Figure 31: straight cutting line is easier for operator but could impact on yield slightly compared with generic saw although this was not evident in the data collected

Figure 32: Integration of system into processing line will be required so operator does not have to pivot 180 degrees

Figure 33: Adjustable table angle allows different settings for different runs of carcases.

6 Results

6.1 Yield Benefits

The yield benefits displayed in the following section are a result of the measurements collected during the site visit. The results displayed in this section are a mix of grass and grain fed carcases, noting that the proportion of these will impact on the yield benefits of the system because the observed manual cut accuracy of grain fed carcasses was higher than for grass fed carcasses.

6.1.1 Ex-Ante Estimations

The three ex-ante scenarios have been used to demonstrate the return on investment with 3 different accuracies for the x-ray beef boning solution. This was conducted to show the payback which can be expected depending on the accuracy of the automated system. The three accuracy scenarios use different standard deviations from their means including 5mm (Ex-ante 1), 10mm (Ex-ante 2) and 15mm (Ex-ante 3).

In order to simulate the ex-ante samples, we have produced a set of random numbers based on the manual data capture using a statistical random number generator. These random numbers are normally distributed from the mean and standard deviation of 5mm (Ex-ante 1), 10mm (Ex-ante 2) and 15mm (Ex-ante 3). Each random sample is equal in size to that of the equivalent manual sample.

The three standard deviations were set to show the estimated payback periods for different systems. Ex-ante 1 is the expected performance of the system as shown by systems previously developed by SAR in the lamb industry and has been used to estimate the overall yield benefits. Ex-ante 2 has been used to show the estimated payback period if the system is slightly less accurate while the systems is being calibrated post installation. Ex-ante 3 has been used to show the payback period for plants if no yield improvements are achieved.

The means each of the cut results data sets have been set independently for each of the cuts and ex-ante studies. The means were established by aligning the 5% percentile mark of each scenario to the most negative acceptable point. For example cut three the 5% percentile market was set at 1mm on the cranial edge of the 5th rib to minimise small pieces of bone.

The current processing speed was used for all the scenarios. However, with the installation of the x-ray solution the boning rate could be increased without losing accuracy. More slicers would be required to do this. This would decrease the payback period for the system because of increased room efficiency.

6.1.2 Cut 3 – Shoulder to Cube Roll Separation

The value attributed to the automation of cut 3 is shown in Figure 34. This graph displays the mean value of loss by the yellow dot and the variation in the value of loss. As can be seen by the manual operation the value of loss varies from $9.84 to $13.68. The variation in the ex-ante 1 is much less with the expected loss being between $2.03 and $2.90. The value used in the analysis is only 30 percent of this amount so as to be conservative.

The square around the mean demonstrates the variation of the manual systems is 4 times the variance expected by ex-ante 1. The difference in price is also a result of a variation in the means; the manual systems mean is an estimated 19mm higher (cube roll sold as chuck roll) when compared to the ex-ante 1 scenario.

The cuts which contribute to the decrease in loss in value seen in Figure 34 are as follows:

- Cube roll ($9.74 to $7.08/hd);
- Short ribs ($0.44 to $0.35/hd);
- Navel end, Kalbi plate and trim ($0.50 to $0.364/hd);
- Back ribs ($0.06 to $0.03/hd);
- Back rib bits ($0.05 to -$0.02/hd);

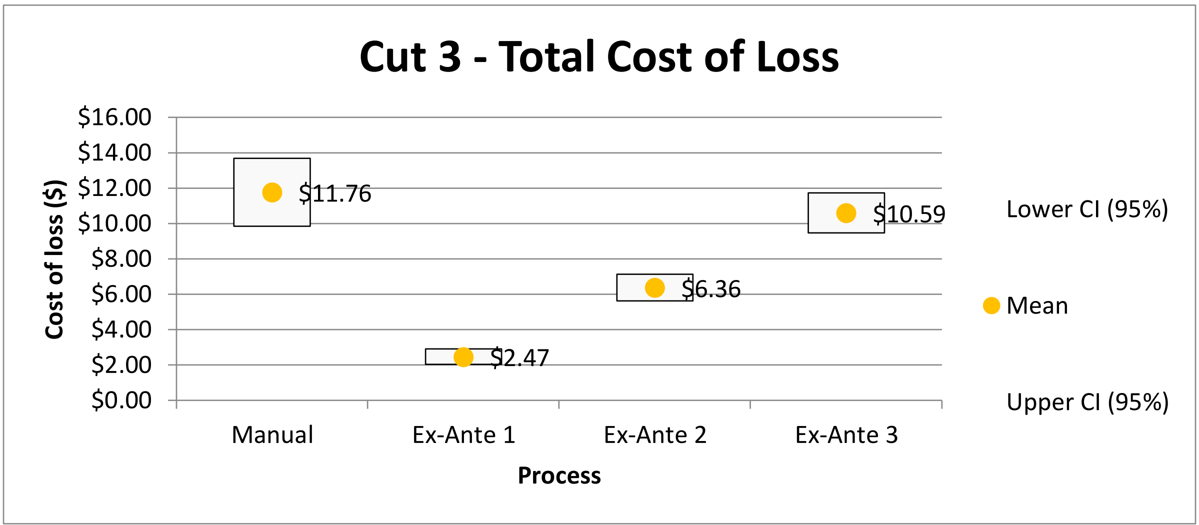


Figure 34: Cost of inaccuracy attributed to Cut 3

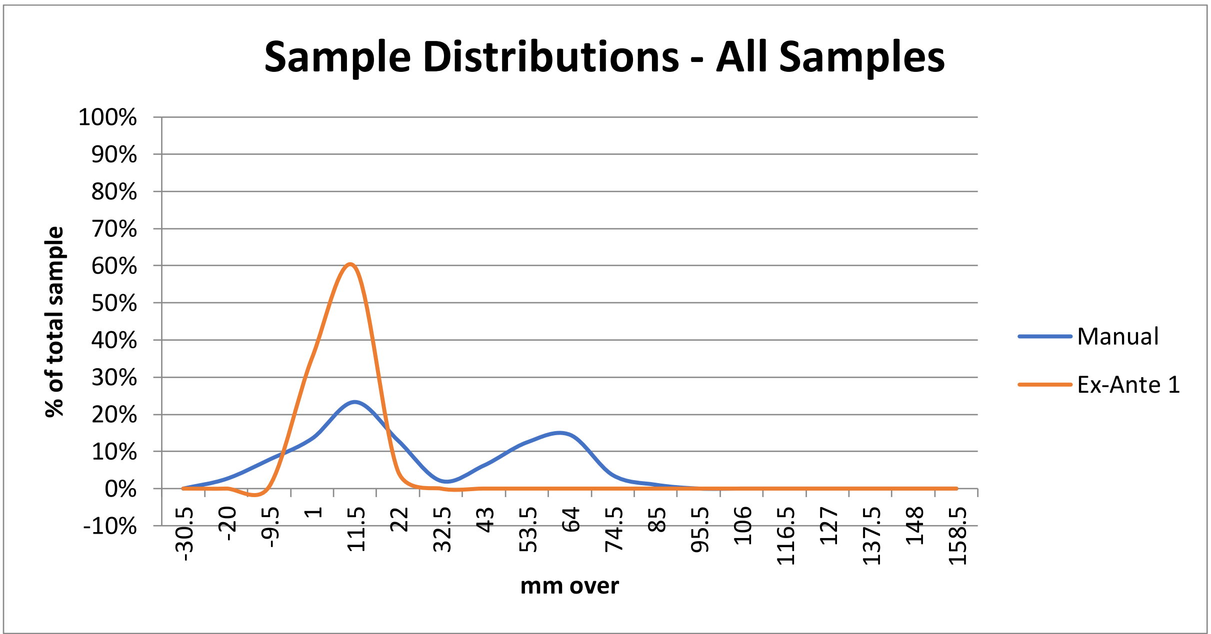


Figure 35: Distribution of samples for cut 3

The variation in the distribution of cut 3 for the manual operator has formed an abnormal distribution. The two peaks in Figure 35 for the accuracy of manual operation reflect the increase in chain speed between grass and grain fed carcases with operators having less time to complete the same job for grass fed carcasses.

If the plant was to slow the chain to increase the accuracy of this manual cut the estimated labour cost increase to the plant is approximately $4.44 per head. Therefore, if the x-ray beef solution is as accurate as estimated in the ex-ante 1 and ex-ante 2 scenarios the payback will increase to between $10.78 and $7.81 per head. Thus, maintaining the faster current line speeds with more accuracy from the x-ray solution for both grass and grain fed carcasses will significantly increase savings for the plant.

As a default, the model has assumed a 10% grain feed and 90% grass fed processing mix.

6.1.3 Cut 1 – Chuck Scribing

The value attributed to cut 1 was calculated at $0.36/hd for ex-ante 1. As can be seen in Figure 36 the automated system on this cut needs to have a standard deviation from the mean of less than 5mm. This has been obtained by similar systems developed by SAR.

The main variation in value of the cuts attributing to the benefits shown in Figure 36, are as follows:

- Increase in weight of intercostals and an increase in number of intercostals greater than 6” in length ($0.009 to $0.004/hd).
- Increased weight of bone and trim sold as chuck ribs ($0.36 to $0.23/hd).
- Increased weight of chuck flap tail and trim ($0.10 to $0.06/hd).

There are a number of cuts which have also shown to decrease in value as a result of the x-ray system and thus the differences between the increases in value of the cuts above.

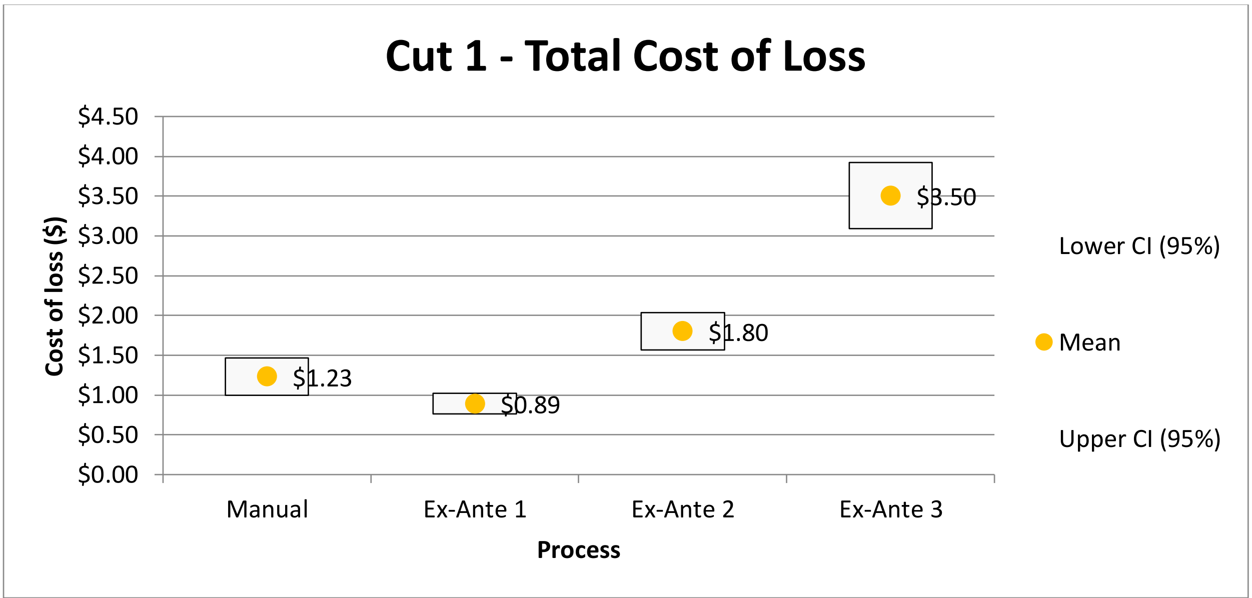


Figure 36: Cost of inaccuracy attributed to Cut 1

6.1.4 Cuts 4, 5, 6, 7 – Rib Scribing

The value attributed to automating cuts 4, 5, 6 and 7 is $1.24 (Figure **37**). The main value attributing to this saving is a result of reducing the variation in the width of back rib by maximising their width on every carcase by reducing the size of the back rib bits and moving cut 4 in a ventral direction.

The main variations in cuts attributing to this benefit are:

- An increased weight of back ribs ($3.52 to $3.13/hd)
- A decreased of weight back rib bits (-$1.27 to -$1.35/hd)
- A decreased weight of bone and intercostal (-$0.66 to -$0.88/hd)
- A difference in weight between trim and subway meat ($0.02/hd)

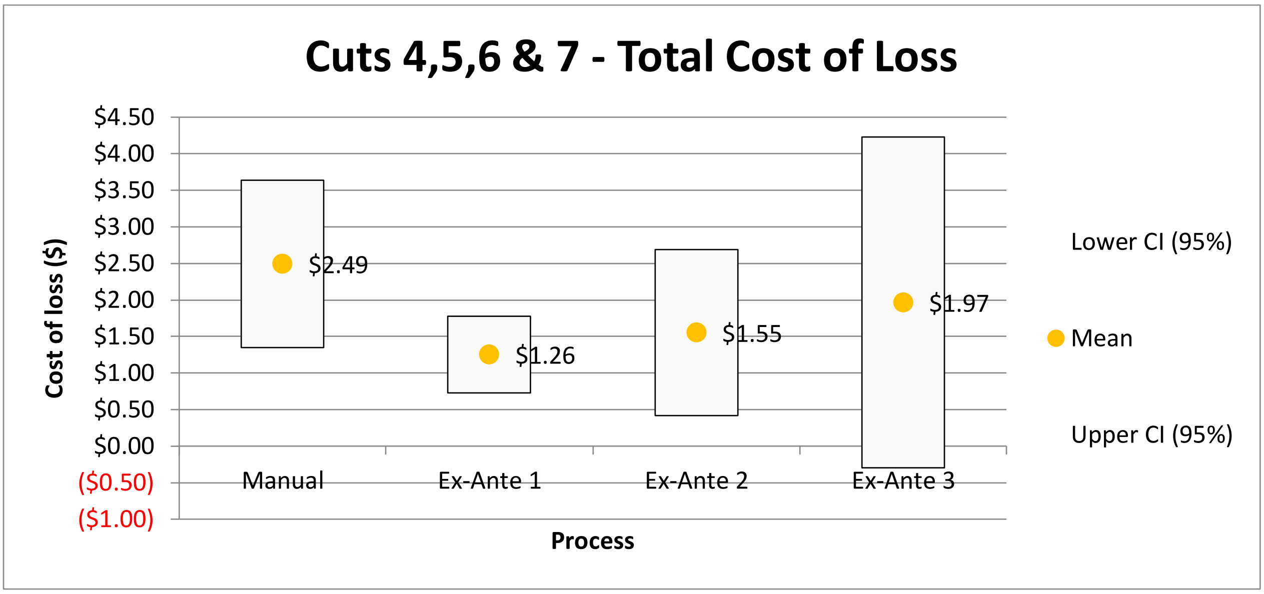


Figure 37: **Cost of inaccuracy attributed to cuts 4, 5, 6 and 7**

6.1.5 Cut 8 – Rump Striploin Separation

The value attributed to the automation of cut 8 is affected by the chain speed. The variation shown in Figure 38 is a combination of rates between 130 and 150 carcases per hour. When the value if these cuts were assessed for the high chain speed the difference in the value between the manual and the ex-ante 1 more than doubled (from $0.13/hd to $0.37/hd). However, when the automated system was compared to the slower chain speed the benefit per head was reduced to nothing.

The only cut attributing value shown in Figure 38 is the increase in the saleable weight of striploin.

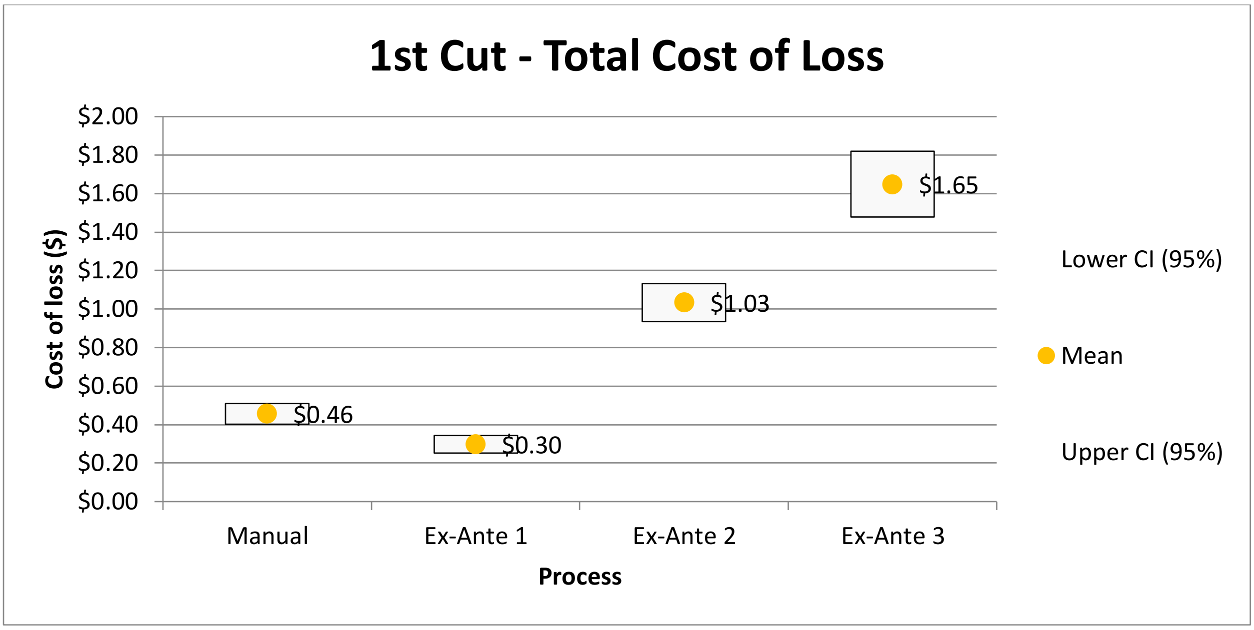


Figure 38: Cost of inaccuracy attributed to cut 8

6.1.6 Aitch bone (Cut 9) & knuckle removal

The net benefit attributed to aitch bone (cut 9) as well as knuckle removal is approximately $3.44 per head based on previous studies. This benefit may be achieved through the installation of commercially available SAR semi-automatic aitch bone and knuckle pullers given the difficulty of fully automating these tasks.

Given the above these tasks and their benefits are not included in this beef automation modelling, as this focusses on novel, fully automated boning tasks. However, the yield and OH&S benefits of the SAR beef puller are significant, and inclusion of these units in any beef automation implementation is highly recommended.

6.1.7 Cuts 6 & 11 - Striploin & Cube Roll Deboning

The key financial driver of profit for this loin de-boning system is the weight of striploin and cube roll (Cuts 6 & 11) sold relative to the starting carcase weight. Weight of saleable striploin is directly impacted by the weight of wiz trim and bone removed from the striploin during the boning process. Comparative weight of these three products (finished striploin, wiz trim, and bone) are the factors used in the primary method for comparing yield between the different systems. A secondary method (comparing weight of finished striploin against hot carcase weight) was also used. Both methods demonstrated an improvement in yield using the loin saw over both table boning and chain boning. However, the range of variables mentioned earlier in Figure 16 when using this second method create more variation in yield than that observed between the three boning methods measured during the trials. The time it takes to track carcases through the whole boning process and conduct full yields required for this analysis limits the sample size for each treatment which was the reason for using both calculation methods.

Table 5 and Table 4 summarise the yields results of all four boning methods using both yield calculations mentioned above. Weight is expressed as a combination of total carcase weights sampled during the trial. Note the “Loin Wgt” column and associated “Yield %” compare weight of finished loin back to hot carcase weight and demonstrate an improvement in yield of 0.13% of total carcase weight for loin saw method as compared to chain boning. There is also a reduction in wiz trim, expressed in the far right column as 3.4% of finished loin weight. This reduction in wiz trim represents an increase of the same percentage in finished striploin weight.

Table 4: Dinmore trials – Comparison of side chain versus loin saw boning methods against carcase weight and loin weight

SUMMARY from "YIELD 16 8 12" Tab	Side wgt	Loin wgt	Yield %	Wiz wgt	Yield %	Wiz trim as % of Loin weight
Side Chain	2151	87	4.05%	4.9	0.23%	5.6%
Loin Saw	2188	92	4.18%	2.0	0.09%	2.2%

Wiz trim savings were observed in further trials as shown in Table 5 where table boning showed a reduction in wiz trim over chain boning of 2.2% of finished loin weight, loin saw showed an additional improvement of 1.5% over table boning and the SAR loin saw showed a further reduction over the generic loin saw of 0.3% of total finished loin weight. Note the expression of loin yield as a percentage of total carcase weight followed similar trends but given the wide range of variables contained in this data is not considered a reliable and repeatable method for the limited size of the data set.

Table 5: Dinmore and Beef City trials 1 thru 4 comparing all four boning methods against carcase weight and loin weight

	Side wgt	Loin wgt	Yield %	Wiz wgt	Yield %	Bone wgt	Yield %	Wiz trim as % of Loin weight
Side Chain	3088	118	3.81%	6.4	0.21%	47.5	1.54%	5.4%
Table Bone	3242	130	4.02%	4.2	0.13%	48.0	1.48%	3.2%
Loin Saw	3363	133	3.95%	2.3	0.07%	48.3	1.44%	1.7%
Scott's Saw	2833	112	3.96%	1.6	0.06%	45.4	1.60%	1.4%

In summary, wizard trim very clearly shows the differences in the boning methods. Side boning produced 200grams of wizard trim while saw boning produced 46grams per side on average. This represents an increase of 150 gram saving in loin meat per side or 300grams per carcase.

The yield retention percentage obtained by the system on the striploin has been used for the basis of the calculations for the cube roll. The yield difference between the between the cube roll and striploin from the overall carcase was using as a ratio to show the reduction in yield benefit obtained for the cube roll. The wholesale price for the cube roll was then used to show the financial opportunity through automated chine removal.

6.1.8 Operations Included

The cuts that have been included in the financial analysis are as follows:

- All vertical scribing cuts (Cuts 1, 4, 5 & 6).
- The shoulder to cube roll separation (Cut 3).
- The striploin to rump separation (Cut 8).
- Chine removal for the cube roll & Striploin (Cuts 6 & 11)

Additional benefits could be obtained from automating the following cuts which have been excluded from the current analysis.

- Separation of the cube roll & striploin due to the requirement to maintain the grading cut.
- Boning out of the hindquarter.
- Fat trimming

6.2 Labour benefits and OH&S

According to Greenleaf's previous reports on beef automation, labour benefits and OH&S benefits from automation are a large portion of the overall benefit from automation. However, the change in operational process can have a negative impact on labour benefits. This is because additional manual labour may be required to facilitate or complement the automated systems, which may offset the labour benefits gained through automation. Hence, the real labour benefits and OH&S benefits depend on the specific layouts of the automation systems being introduced to a plant.

Therefore, in this CBA Model, it is assumed that the best-case scenario is used for labour benefits and OH&S benefits. These assumptions will need to be validated by manufacturers, systems designers, and industry participants in the future.

6.2.1 Australian labour wages and OH&S trends in the next 20 years

Australia's labour wages and OH&S claims are expected increase by 60% in the next 20 years (Figure 39). This will also lead to an increase in claims cost by more than 80%, because the increase in costs associated with the OH&S are closely associated with the increase in wages. Therefore, the price competitiveness of Australian beef products will continue to erode in the next 20 years due to the increase in labour costs. The benefits achieved through labour & OH&S will need to be reviewed once the systems have been developed, since the technical capability of the systems will affect the overall benefit.

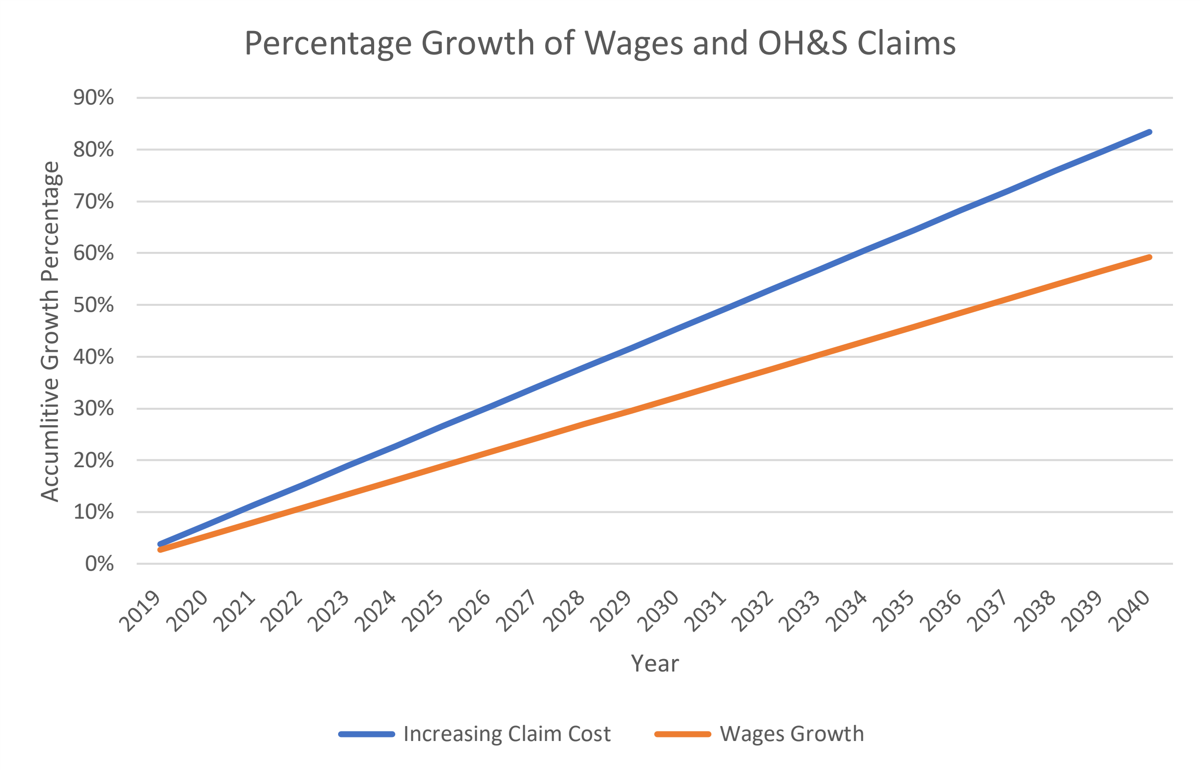


Figure 39: Percentage Growth of Wages and OH&S Claims

6.3 Throughput Benefits

The amount of throughput benefits for beef processors is dependent on whether the processor plant employs a timed process or not. A timed process is where all stations move in synchronicity based on a timer. This type of processing line would not benefit from a throughput saving from automation, because any throughput increase will be offset by the timer. Unless the timer is changed to reflect the overall increase in throughput through all stations, individual throughput increases from automating specific stations will not see throughput benefits. On the other hand, chain systems that move continuously along the line might see throughput benefits from automation by increasing the processing speed at each station and increasing the speed of the line.

Another factor affecting the throughput with automation is line bottleneck. The misalignment between individual automation systems and manual labour could create these bottlenecks. By strategically positioning automated systems at key production bottlenecks, automation can help to alleviate these bottlenecks and increase overall throughput. Additionally, machine-to-machine communication can mitigate the effects of bottlenecks as the product transitions from one system to another.

It was observed that line speeds varied depending on whether grass or grain fed carcasses were being processed. The slower processing of grain fed carcasses allowed more accurate manual cuts, and hence less yield difference (and associated yield benefits) between a manual and automated scribing system. However, it is likely that an accurate automated scribing system would allow a faster line speed for grain fed carcasses, with consequent increased throughput.

Currently, there is not enough data to determine the throughput benefits of beef automation, therefore there has been no throughput benefit included. Based on previous lamb automation systems, there has been a considerable throughput increase of up to 28%, with no additional labour. As the data becomes available, the data for throughput benefits will be adjusted accordingly.

7 CBA Results

The cost benefit results obtained through the project are associated with a range of cuts being completed for each of the three main components being considered. For each of these systems there are smaller and larger systems which will suit medium and large throughput plants respectively. The two main two areas covered in this section of the report are: 1) system capabilities and considerations for their development, and 2) the cost benefit analysis for each of the six components.

The systems reviewed and the cuts which they are to complete are listed below (see Figure 1 for cut numbers).

- Beef Scribing System – Module 1
    - Vertical beef scribing include cuts 1, 4, 5 and 7. These cuts have already been automated with a system currently operational in Australia.
    - Horizontal beef scribing include cuts 3 and 8. Cut 2 is currently completed prior to carcases entering the boning room, which is required for carcase grading. Cut 8 is only completed in some plants but would need to be completed to allow the beef chining system to chine the striploin.

- Beef Chining System – Module 2
    - Chine boning removal from the Striploin & Cube roll (Cuts 6 & 11).
    - Button bone removal

- Integrated Single/Dual Rail System
    - The integrated system will link the above beef chining and scribing systems into one integrated system, but at this stage does not include any additional tasks or cuts. Hence only estimated capital costs for integration are included with no yield, throughput or labour benefits assumed.

- SAR beef puller
    - The commercially available aitch-bone and knuckle puller is an optional add-on that could be added but the estimated net benefit of $3.44/hd and associated costs have not been included in the modelling.

7.1.1 Beef Scribing System - Module 1

The beef scribing module is comprised of two components, the vertical and horizontal cutting lines. The following section outlines the technical considerations which will influence the value created by each component. The benefit of all cuts using the current processing has been included in the cost benefit result. Some additional benefits have also been identified for each cut but not included in the CBA result.

7.1.1.1 Vertical Cuts

The technical capabilities of the beef scribing system will affect the cuts completed by the system. The current beef scribing technology has limitations that prevent some cuts being completed by the system, such as cut 7. This removes the back-rib bits from the back ribs and is currently completed post cube roll removal to ensure the cube roll is not cut by the saw. The calculations presented only include the benefits from cutting the meat and bone component at the same time.

However, if the scribing system could be developed to only cut the depth of the ribs the width of the back ribs and short ribs could be maximized to increase the overall value of the carcase. This is the case for all the vertical cuts on the carcase as the meat and bone components of the rib cage can be cut in separate locations to maximise their value.

7.1.1.2 Horizontal Cuts

The value created through the horizontal cuts has always be affected by the ability to breakdown the carcase. As technology progresses it may allow these cuts to be completed in relation to the quality of the muscle not the ability to breakdown the carcase. The major cutting lines are as follows:

- Shoulder to Cube Roll. The benefit of cutting this cut in its current method has been included in the CBA results.
- Cube Roll to Striploin. This cut is currently completed in the chiller to allow the cube roll to bloom for grading purposes. The value of this cut has not been included in the cost benefit analysis as it requires an un-invasive grading technology to replace the current method.
- Striploin to Rump, this cut is governed by the aitch bone and value will only be created by cutting on the point of the bone or conducting a scallop cut. Only the value of a straight cut is included in the results. This cut is not completed in some chain boning plants but will need to be completed to utilise the chining module.

Forequarter to Cube Roll Technical Considerations

The curved nature of this cut is required to ensure maximum yield of the cube roll, navel end brisket, short ribs, back rib bits and back ribs. Currently, the operators split the vertebrae and then twist the carcase to get as close to the cranial edge of the 5th rib as possible.

The variation observed in cut 3 is shown in (Figure 1) by the yellow lines; the ideal location for this cut is shown by the green line. The standards for this cut were developed to establish the loss of yield from the cube roll, short ribs, back ribs, and the back-rib bits.

The installation of the X-ray beef solution will add value to this cut by increasing the accuracy of the cut placed along the edge of the 5th rib. The robot will identify the edge of the 5th rib and guide the blade to precisely cut along the edge of the rib. This will decrease the chance of bone fragments ending up in trim by conducting this cut using an automated knife.

Only 30% of the estimated benefit of this cut was previously associated with the cut's total benefit, because technical capabilities for the system during the previous trials had limited the benefit. The same value has been included in this project. However, it is important to consider that additional benefit could be obtained as the technology advances.

7.1.2 Beef Chining System - Module 2

The chining process cut currently requires manual boning with a knife. An automated beef chine bone removal system would be similar to the lamb LEAP IV system by using circular saws to cut the ribs. However, the anatomical curvature of the ribs will need to be taken into consideration when automating this process. An x-ray imaging system would be required to identify the curvature for each carcase and acquire the data for the best cutting lines.

An additional 1.4% yield could be obtained over and above the currently used estimate. Previous studies completed on the beef chine removal has shown that only 98.6% of striploin & cube roll could be retained from the rib bones. Therefore, if the accuracy of the proposed system can pick-up the additional 1.4% yield the benefit for the system could increase by a further $1.65/ head.

The accuracy of the system would need to be considered in the development of this system. The following identifies the technical assumptions in relation to the benefit of the chining machine.

- The value of chining has been initially costed for only the strip loin in previous work, thus the value of yield benefits for the cube roll will significantly increase the total opportunity.
- The estimated yield increase for the cube roll has been calculated by using the same yield increase on a carcase basis for the striploin but also using the ratio between the standard yield of the striploin and cube roll.
- The price difference between the cube roll and striploin was also included to show the variation in value as a result of the cube roll value rather than the striploin's value.
- Potential fat trimming system benefit has not been included and would need additional work completed if the benefits are to be included.

7.1.3 Technical considerations

The integration of module 1 and module 2 may provide additional benefits that are much greater that what is possible using the current carcase breakdown method. The horizontal cutting locations have always been governed by major anatomical structures which have governed the ability of the current technology to breakdown the carcase into manageable sized pieces. The utilisation of objective measurement technology together with robotic arms that increase our ability to move half carcases weighting over 150kg needs to be considered through the development process.

Changing the location of the cutting line between the striploin and the cube roll has been discussed with several participants during the project. The development of advanced boning technology to allow cuts to be completed using objective measurement technology will increase the value of the benefits over and above the current. The chuck to cube roll cutting line may also increase have an increase in the value if this technology could cut carcases on meat quality rather than anatomical structures. These changes would result in considerable modifications to the current process flow but also could come with considerable benefits. The benefits associated with this method of carcase breakdown has not been included as it is outside the scope of the project. Any further value created through this process has not been previously calculated and hence would require a considerable amount of work to provide an accurate estimation.

The benefit of the CBA results for chining are lower than for the scribing system but if the above technical constraints can be overcome, the chining system line would be integral to the separation on the boning chuck, cube roll and striploin and may provide larger yield benefits.

7.1.4 Integrated System

The layout of the plants will determine the placements of fully automated and integrated systems and the ways in which a plant operates. However, this modelling has assumed three integrated system configurations being single rail, dual rail and carousal, with each suited for a particular plant size and application.

With new plant layout methods and disruptive technologies, new products could be created that changes the way carcases are cut up. Additionally, the technical capabilities and the potential impact on capital costs are explored. Figure 40 has been developed by SAR which presents major assumptions on the technical capabilities of each system.

7.1.4.1 Single Rail System

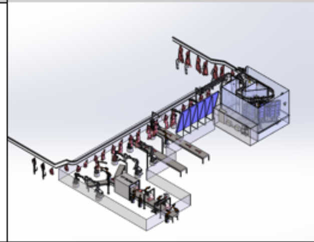
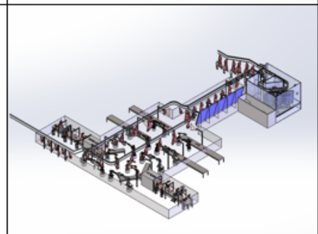
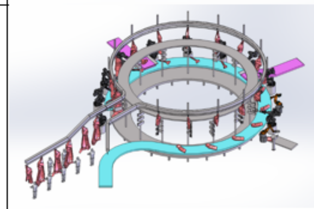
The single rail layout consists of a single line with automated systems being placed along the line. This system eliminates scribing operators and allows manual operators to operate alongside automated systems. The system has the lowest capital cost, the yield benefits are identical but the labour savings per head will be slightly higher between this system and the dual rail. This configuration is specifically designed for lower throughput plants. The simplicity of the single rail layout will allow greater accessibility from the industry

7.1.4.2 Dual Rail System

The dual rail option consists of two parallel lines that allow simultaneous processing. This allows a high throughput rate and enables manual operators to work in parallel with automated systems.

The dual rail option is more expensive and more complicated compared to single rail systems, but it provides a higher throughput resulting in an overall increase in the return on investment of the system. The DEXA and CT sensing system will be able to serve both rails without incurring double the cost compared to the single rail system.

Figure 40: Systems in the pipeline of development by SAR

NR	Description	Labour saving [$/year]	H&S saving [$/Year]	Capital Costs [$]	Accuracy "Cutting in the right place without devaluing higher value meat"	Yield [$/year] "not leaving meat on the bone"	Payback 240 days/year 2 shifts	Process	Picture	Advantages	Disadvantages	Output
	BEEF AUTOMATION				Based on MLA report p.pip.036 average of $13.06 per HD or $6.53 per side	Based on $2.50 per Beef Head(Ex 303 Project : Loin Options Evaluation)Fat removal, Button						
BF3000-002 Single Rail Option	Scribing , No Banjo Leg Removal, No Brisket Removal,@ 10 sec cycle Time. 3 sides per min,180 sides per hr,1350 sides per shift , 650 HD per shift.	$ 336,000	$ 80,000	$ 10,599,500	$ 3,834,332	$ 734,265	1.5	1. X Ray 2.Scribing 3.Brisket Removal 4. FQ Separation 5. Rack Separation 6.Thin Flank Removal 7. Loin Separation 8. Loin & Rack Line 9. HQ on Rail		Accurate Scribing or marking on beef Side. Eliminates Scribing Operators. Variable Scribe lines for Manual or Auto Processing.	Production rate is half the rate Dual Rail Option. Redatuming of Beef Side between X Ray room and cutting stations.	
BF3000-001 Dual Rail Option	Scribing & Cutting @ 20 sec cycle Time. 6 sides per min,360 sides per hr,2700 sides per shift , 1350 HD per shift.	$ 336,000	$ 80,000	$ 16,721,700	$ 7,668,664	$ 1,468,530	1.9	1. X Ray 2.Scribing 3.Brisket Removal 4. FQ Separation 5. Rack Separation 6.Thin Flank Removal 7. Loin Separation 8. Loin & Rack Line 9. HQ on Rail		Accurate Scribing or marking on beef Side. Eliminates Scribing Operators. Variable Scribe lines for Manual or Auto Processing.	Cost of Equipment is twice the cost of the Single Rail Option. Larger Floorprint.Redatuming of Beef Side between X Ray room and cutting stations.	
BF3200-001 Carousel	Scribing & Cutting @ 15 sec cycle Time. 4 sides per min,240 sides per hr,1800 sides per shift , 900 HD per shift.	$ 336,000	$ 80,000	$ 11,529,500	$ 5,112,442	$ 979,020	1.3	1. CT Scan 2.Brisket Removal 3. FQ Chuck Ribs 4. FQ Separation 5. Rack Short Ribs Removal 6.Rack Cube Roll Removal 7.Rack Back Ribs Removal 8. Thin Flank Removal 9.Loin Fat Removal 10.Loin Separation + Chine Removal 11.Loin Button Removal 12.HQ on Rail		Accurate Scribing or marking on beef Side. Eliminates Scribing Operators. Variable Scribe lines for Manual or Auto Processing. Scan and Datuming in the same station.	Internal Fixturing of clamping of product to cope with size change.	

7.2 Carousel System

The carousel option has been excluded from the analysis as communication with program managers within MLA has indicated that this is the least likely to be implemented. This option is less configurable, less flexible, and more expensive. It is estimated that the capital cost, cutting accuracy and yield benefits fall between the Single Rail and Dual Rail Systems

7.3 Capital Costs Considerations

The capital costs of the integrated or stand-alone modular systems are directly related to the complexity and value of the cut involved, the maturity of the technology, the R&D time period, and the estimated return on investment. They will depend on:

- **Robotics**: Depending on the robotic technology, off the shelf products can be configured for processing. On the other hand, completely new software systems could be necessary to achieve automation.
- **Integration**: The integration of various robotic systems would require significant plant reconfiguration and software integration. Modular designs are more expensive to design and implement.
- **Imagery**: The range of existing and upcoming sensing technology, as well as the software will determine the cost of the system. The cost can be reduced by using a single sensing system that integrates with multiple automated modules.
- **Other Capital:** Other capital costs such as human resources required to design and implement the system, installation and calibration, maintenance and repair, and imagery systems.

Table 6: Capital cost breakdown of systems included in the CBA results.

Component	Integrated		Beef Scriber		Chining	
	Larger System	Smaller System	Larger System	Smaller System	Larger System	Smaller System
Capital Cost of Main						
Beef Scriber	$ 8,971,700	$ 3,399,500	$ 8,971,700	$ 3,399,500		
Chining	$ 4,000,000	$ 4,000,000			$ 4,000,000	$ 4,000,000
Imagry Costs						
DEXA	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ -	$ -
CT	$ 1,500,000	$ 1,500,000	$ -	$ -	$ 1,500,000	$ 1,500,000
Other Installation Costs						
Essential and insurance spares	$ 500,000	$ 500,000	$ 300,000	$ 300,000	$ 200,000	$ 200,000
Integration	$1,000,000	$ 750,000	$ -	$ -	$ -	$ -
Other Capital install	$ 1,000,000	$ 1,000,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000
Total	$ 17,471,700	$ 11,649,500	$ 10,271,700	$ 4,699,500	$ 6,200,000	$ 6,200,000

The additional capital costs shown in Table 6, which is not included in Figure 40, have been included to allow for installation costs. These values will vary between plants.

7.4 Financial Results

The cost benefit analysis conducted on the ex-ante value proposition of automated beef boning has been completed for medium and large plants. The scribing, chining and integrated systems have been included in each analysis. The main differences are:

- The system design to enable the required throughput.
- The capital cost and overall benefits vary which reflect the variation in throughput volume.

The detailed results in this section all relate to the single rail system. The high-level results have been presented for both systems.

7.4.1 Financial Benefits of System

7.4.1.1 Single rail system benefits

The summary results in Table 7 demonstrate the benefit of the integrated single rail, beef scribing and chining systems over manual performance. The increased value came from yield benefits, OH&S savings and labour savings. There has been no increase in the efficiency (throughput) of the boning room factored into the cost benefit analysis.

The net benefit expected for the integrated single rail system was $13.11 to $14.72/hd. This delivers an estimated return on investment of between 1.94 and 2.13 years depending on the accuracy of the automated system.

The imagery systems included in the chining module has not been confirmed by the system manufacturer at the time of this report. They are currently assessing the use of either x-ray or CT for imagery purposes. If x-ray can be utilised for this system, the capital cost will be reduced by $1 million.

Table 7: Summary of benefits for the smaller beef automation solution

SUMMARY PERFORMANCE MEASURES						
	Single rail		Beef scribing		Chining	
Hd / annum	328,320		328,320		328,320	
Production increase with equipment	8.20%		3.13%		3.13%	
	Avg.	To	Avg.	To	Avg.	To
Capital cost (pmt option, upfront)	$11,649,500		$4,699,500		$6,200,000	
Gross return Per head	$17.17	$18.78	$7.57	$9.18	$9.22	$9.22
Total costs Per head	$4.06		$1.69		$2.13	
Net Benefit Per head	$13.11	$14.72	$5.88	$7.49	$7.09	$7.09
Annual Net Benefit for the plant	$ 4,304,063	$ 4,832,108	$ 1,929,531	$ 2,457,576	$ 2,326,672	$ 2,326,672
Annual Net Benefit for the ex cap	$ 5,469,013	$ 5,997,058	$ 2,399,481	$ 2,927,526	$ 2,946,672	$ 2,946,672
Pay back (years)	2.13	1.94	1.96	1.61	2.10	2.10
Net Present Value of investment	$31,889,801	$35,967,222	$14,483,580	$18,561,001	$17,171,162	$17,171,162

7.4.1.2 Dual rail system benefits

Table 8 presents the financial benefit for the dual rail system to be utilised by larger plants which has doubled the processing capacity compared to the single rail system. The net benefit of the system is between $13.95 and $15.55/ hd. This presents a payback period of between 1.46 & 1.60 years for the dual rail beef automation system.

When comparing the gross and net benefits between the larger and smaller systems, it can be identified that the gross benefit per head is higher for the smaller plant but the net benefit is lower. This is due to the higher cost of automation per head for the lower throughput and the higher labour benefit per head for the smaller plant. The higher labour benefit per head for the smaller plant is due to a higher cost per head labour for the manual operations.

Table 8: Summary of benefits for the larger dual rail system, beef scribing and chining systems retrofitted for a larger throughput plant.

SUMMARY PERFORMANCE MEASURES						
	Dual Rail		Beef scribing		Chining	
Hd / annum	656,640		656,640		656,640	
Production increase with equipment	9.89%		4.17%		3.09%	
	Avg.	To	Avg.	To	Avg.	To
Capital cost (pmt option, upfront)	$17,471,700		$10,271,700		$6,200,000	
Gross return Per head	$16.88	$18.48	$7.51	$9.11	$9.00	$9.00
Total costs Per head	$2.93		$1.69		$1.07	
Net Benefit Per head	$13.95	$15.55	$5.82	$7.42	$7.93	$7.93
Annual Net Benefit for the plant	$ 9,158,123	$ 10,211,209	$ 3,818,833	$ 4,871,919	$ 5,210,200	$ 5,210,200
Annual Net Benefit for the ex cap	$ 10,905,293	$ 11,958,379	$ 4,846,003	$ 5,899,089	$ 5,830,200	$ 5,830,200
Pay back (years)	1.60	1.46	2.12	1.74	1.06	1.06
Net Present Value of investment	$68,103,292	$76,234,939	$27,802,774	$35,934,421	$39,436,998	$39,436,998

The following results are all for the smaller of the two integrated system options, however the benefit per head are the same between the two systems except for the labour benefit.

7.4.2 Detailed benefits - Medium Plant

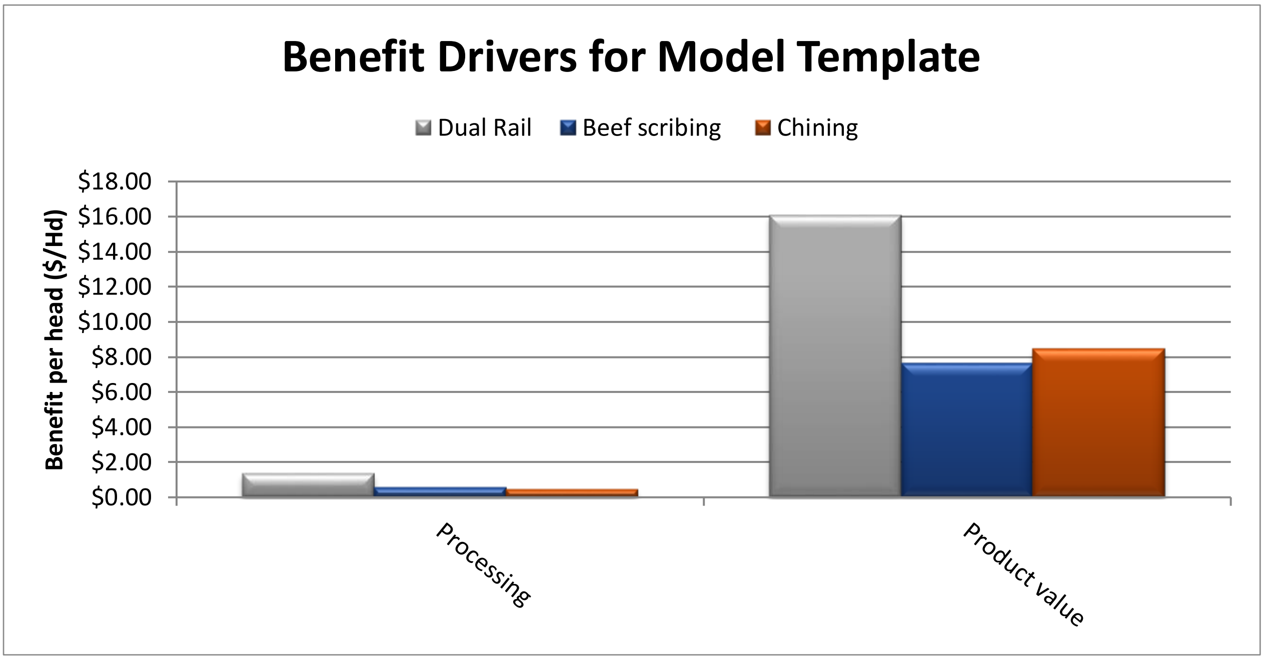


Figure 41: Broad grouping of benefits delivered by the beef automation solution

The main benefits of the automated cutting technology are the increase in yield and a reduction in labour units required. OH&S will reduce by removing bandsaws. There may be small yield gains through reduced bandsaw dust and shelf life, but these have not been included. The contribution of each individual benefit is summarised in Figure 42 and Table 9.

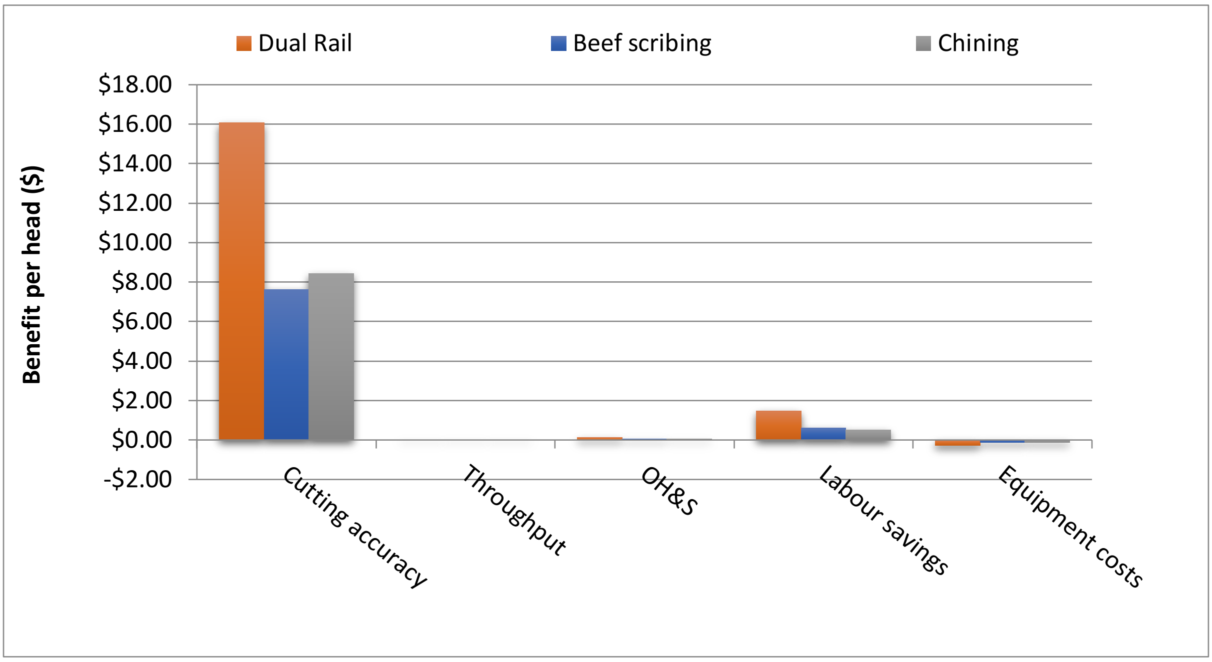


Figure 42: Summary of benefits expected to be delivered from the beef automation solution

Table 9: Breakdown of benefits and costs by area

Benefit Drivers for System						
	Single rail		Beef scribing		Chining	
	$/ hd	$/ annum	$/ hd	$/ annum	$/ hd	$/ annum
Processing	$1.36	$447,252	$0.45	$148,268	$0.54	$176,124
Product value	$16.10	$5,285,784	$7.66	$2,515,235	$8.44	$2,770,548
	$17.46	**$5,733,036**	**$8.11**	**$2,663,504**	**$8.98**	**$2,946,672**
Cutting accuracy	$16.10	$5,285,784	$7.66	$2,515,235	$8.44	$2,770,548
Throughput	$0.00	$0	$0.00	$0	$0.00	$0
OH&S	$0.22	$72,727	$0.09	$29,091	$0.09	$29,091
Labour savings	$1.66	$544,050	$0.62	$203,993	$0.69	$227,033
Labour savings - Relocated	$0.00	$0	$0.00	$0	$0.00	$0
Equipment costs	-$0.52	-$169,525	-$0.26	-$84,815	-$0.24	-$80,000
	$17.46	**$5,733,036**	**$8.11**	**$2,663,504**	**$8.98**	**$2,946,672**

A summary of the range in costs and benefits for each scenario are included in Table 10 below.

Table 10: Costs and benefits breakdown for the current ex-ante review

COST - BENEFIT ANALYSIS OF SYSTEM	Single rail		Beef scribing		Chining	
Benefit summary	$/hd		$/hd		$/hd	
	Avg.	To	Avg.	To	Avg.	To
$ Accuracy Benefit per head	$15.30	$16.90	$6.86	$8.47	$8.44	$8.44
$ Technique Benefit per head	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
$ Labour Benefit per head	$1.88	$1.88	$0.71	$0.71	$0.78	$0.78
$ Overall Benefit per head	**$17.17**	**$18.78**	**$7.57**	**$9.18**	**$9.22**	**$9.22**

** Cost is reported as the inaccuracy from target specification OR as the difference between Manual vs. Auto costs*

COST ASSOCIATED WITH OPERATING SYSTEM	Single rail	Beef scribing	Chining
	$/hd	$/hd	$/hd
Capital cost	$3.55	$1.43	$1.89
Maintenance	$0.00	$0.00	$0.00
Operation	$0.47	$0.26	$0.24
Risk of mechanical failure	$0.04	$0.00	$0.00
Total cost per head	$4.06	$1.69	$2.13
Total cost per head (EX CAP)	$0.52	$0.26	$0.24

Table 11 shows the range in value associated with each cost of processing including breakdown of value opportunity for each cutting line. The cost is calculated as any loss from the maximum benefit possible. Throughput cost is the cost of labour for the boning process. Presenting the figures this way in the detailed section of the model demonstrates the total costs involved and highlights areas where future savings could be generated.

Table 11: Summary results of individual costs associated with the Beef Automation solutions

TOTAL BENEFIT		Single rail		Beef scribing		Chining	
Benefit summary		$/hd From	$/hd To	$/hd From	$/hd To	$/hd From	$/hd To
1.1 Accuracy	Cut 1- Forequater Scribing	$ 0.34	$ 0.44	$ 0.34	$ 0.44	$ -	$ -
	Cut 3- Shoulder Loin Separation	$ 5.25	$ 6.13	$ 5.25	$ 6.13	$ -	$ -
	Cuts 4,5,6,7- Rib Scribing	$ 1.11	$ 1.73	$ 1.11	$ 1.73	$ -	$ -
	Cut 8- Hind Leg Removal	$ 0.16	$ 0.17	$ 0.16	$ 0.17	$ -	$ -
	Chining- Loin Deboning	$ 8.44	$ 8.44	$ -	$ -	$ 8.44	$ 8.44
2. Throughput benefit		$ -	$ -	$ -	$ -	$ -	$ -
3. OH&S benefit		$ 0.22	$ 0.22	$ 0.09	$ 0.09	$ 0.09	$ 0.09
4. Labour benefit		$ 1.66	$ 1.66	$ 0.62	$ 0.62	$ 0.69	$ 0.69
Equipment costs	**Maintenance**	$ -	$ -	$ -	$ -	$ -	$ -
	Operation	$ (0.47)	$ (0.47)	$ (0.26)	$ (0.26)	$ (0.24)	$ (0.24)
	Risk of failure	$ (0.04)	$ (0.04)	$ -	$ -	$ -	$ -
	$ Benefit per head	**$16.66**	**$18.27**	**$7.31**	**$8.92**	**$8.98**	**$8.98**
$ Annual Benefit overall plant		**$5,469,013**	**$5,997,058**	**$2,399,481**	**$2,927,526**	**$2,946,672**	**$2,946,672**

Figure 43 shows the difference in annual benefits for each system. Thickness of the box in the graph represents the upper and lower variation in value based on performance variation captured in the data.

The slightly higher yield benefit for chining is due to the chine removal from the cube roll being included, whereas previous studies have only included the chine removal off the striploin.

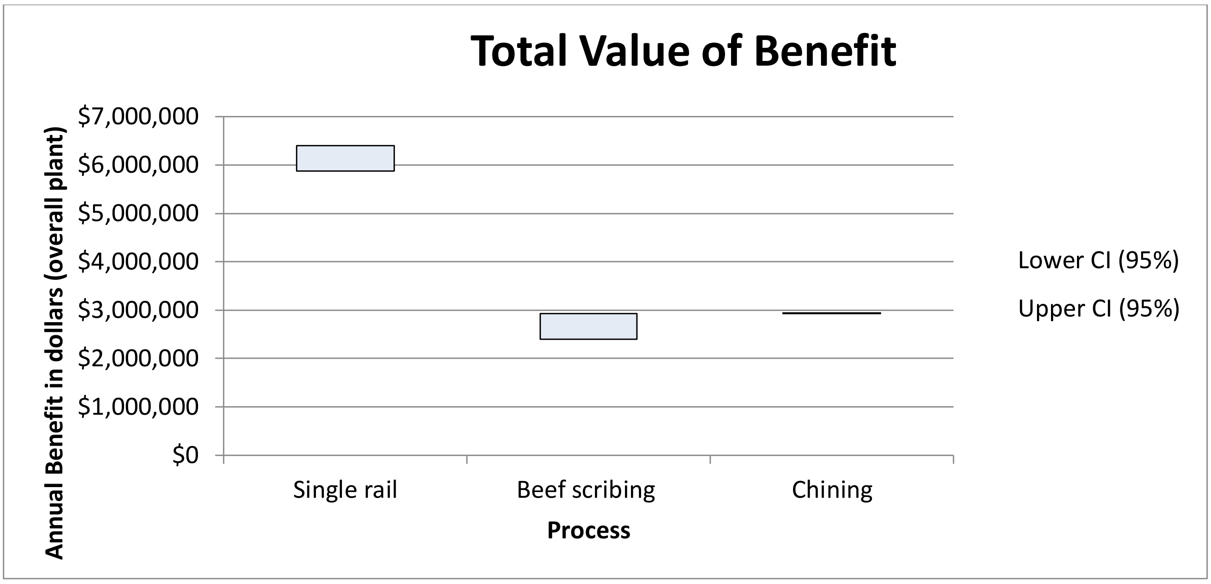


Figure 43: Graphical representation of losses captured in Table 4

Based on the assumptions above, Table 12 shows OH&S benefits. The estimated OH&S savings that can be achieved through the installation of the automated system is up to $0.26 per head. These costing do not include the trauma which can be caused through amputations as this is very difficult to cost.

Table 12: OH&S Benefits of the Beef Automation solution

OH&S				
Job Role Affected				
Claims in last 10 years	**Manual**	**Single rail**	**Beef scribing**	**Chining**
Risk / FTE / Year				
Annual Premium				
Job Annual Hours	14,592	14,592	14,592	14,592
Limb Losses per year	0.20	0.20	0.20	0.20
Sprains and Strains per year	3.00	3.00	3.00	3.00
Annual Cost	$960,000	$960,000	$960,000	$960,000
Annual Cost / Head	$2.924	$2.702	$2.835	$2.835
Annual saving per head	$0.000	$0.222	$0.089	$0.09

The current boning room chain employs 6 bandsaw operators and one scribing knife throughout the chain with 4 bandsaws being used on the forequarter. Through the removal of these saws it will decrease the risk level of the room.

7.4.3 Operational Costs

Table 13 shows the total cost of the equipment including both capital and operational costs.

Table 13: Estimated capital and operating costs of beef automation system

Capital Cost	Manual		Single rail		Beef scribing		Chining	
	Cost	Life span	Cost	Life span	Cost	Life span	Cost	Life span
Beef Scriber			$ 3,399,500	$ 10	$ 3,399,500	$ 10	$ -	$ 10
Chining			$ 4,000,000	$ 10	$ -	$ 10	$ 4,000,000	$ 10
Imagry Costs			$ -	$ 10	$ -	$ 10	$ -	$ 10
DEXA			$ 500,000	$ 10	$ 500,000	$ 10	$ -	$ 10
CT			$ 1,500,000	$ 10	$ -	$ 10	$ 1,500,000	$ 10
Other Installation Costs			$ -	$ 10	$ -	$ 10	$ -	$ 10
Essential and insurance spares			$ 500,000	$ 10	$ 300,000	$ 10	$ 200,000	$ 10
Integration			$ 750,000	$ 10	$ -	$ 10	$ -	$ 10
Other Capital install			$ 1,000,000	$ 10	$ 500,000	$ 10	$ 500,000	$ 10
Total			**$11,649,500**		**$4,699,500**		**$6,200,000**	
Service maintenance	Manual		Single rail		Beef scribing		Chining	
	Units	Cost	Units	Cost	Units	Cost	Units	Cost
Estimated - COSTS								
Electricity	6.00 KW	$0.22 /KWH	6.00 KW	$0.22 /KWH	6.00 KW	$0.22 /KWH		$0.22 /KWH
Maintenance labour (Daily)		743.76 /Yr		150000.00 /Yr		80000.00 /Yr		80000.00 /Yr
Maintenance labour (Preventative)		56985.60 /Yr		0.00 /Yr		0.00 /Yr		0.00 /Yr
Maintenance labour (Breakdown)		0.00 /Yr		0.00 /Yr		0.00 /Yr		0.00 /Yr
Maintenance labour (Training)		0.00 /Yr		0.00 /Yr		0.00 /Yr		0.00 /Yr
Operational		**$62,545**		**$154,815**		**$84,815**		**$80,000**
Maintenance		**$0**		**$0**		**$0**		**$0**
Annual Sub Total (excluding major overhaul costs)		**$62,545**		**$154,815**		**$84,815**		**$80,000**
Total Annual Estimated Expenses	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost
Expected downtime hours per year	0	0.00 /Yr	7	14709.94 /Yr		0.00 /Yr		0.00 /Yr

The risk of down time shown in Table 13 is the estimated cost of down time for an average installation across the wider industry and has been calculated as follows. The allowance is made for 1 occurrence per week where the stoppages associated with the equipment would cause the entire room to be at a standstill for 15 minutes. The same labour cost used for calculating increases in labour efficiency.

8 Automation Strategy

8.1 Stages of Adoption

The development of an automated boning solution could create new ways of breaking a carcase and to optimise value between cutting lines that has been constrained by traditional manual methods. Identifying and modifying cutting lines with image analysis that account for difference in carcase size as opposed to anatomical location could increase the saleable value of a number of cuts.

8.2 Horizons

The beef automation schedule will be broken down into three horizons.

Table 14: Timetable of beef automation horizons

Horizons	**Time**	**Assumptions**	**Cuts**
Horizon 1 (stage 1 systems)	2019-2025	- High value cuts - Large to medium plants - Full automation - Medium to low technology difficulty	- Scribing Point End Brisket (Cut 1) - Striploin to Cube Roll (Cut 2) - Shoulder to Cube Roll (Cut 3) - Chine Bone Removal (Cut 6)
Horizon 2	2025-2030	- Medium to lower value cuts - Large, medium, small plants - Full automation - Medium technology difficulty	- Removal of ribs and feather bone from cube roll (cut 6)
Horizon 3	2030-2035	- Medium value cuts - Large, medium, small plants - Full automation - High technology difficulty	- Foreleg boning - Hind leg boning

The timeline of beef automation includes the previous LEAP systems from lamb automation and provides a holistic overview of the past and future implementation strategies for lamb and beef automation (Figure 44).

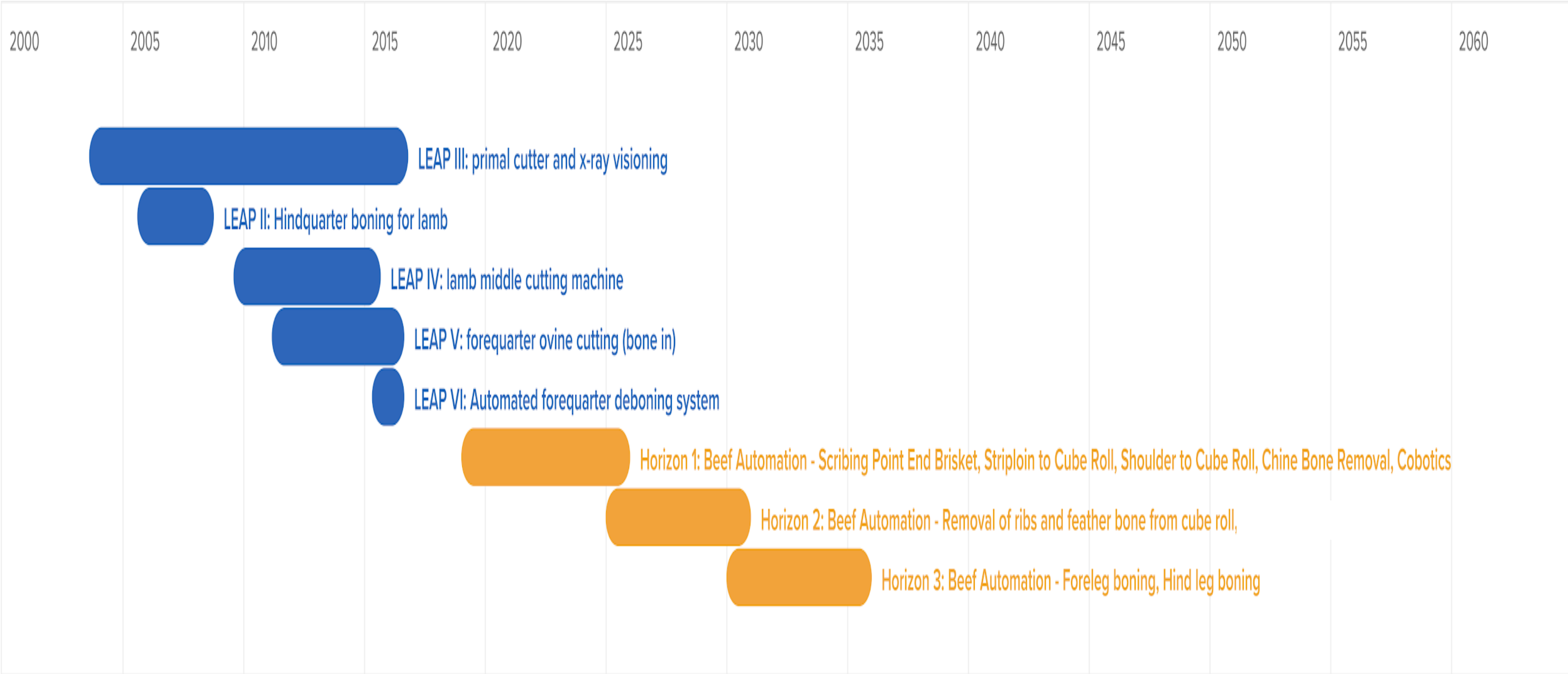


Figure 44: Timeline of lamb automation and beef automation

8.3 Horizon 1: (2019-2025)

8.3.1 Assumptions

- **High value cuts:** are considered for Horizon 1 because they contribute to the greatest ROI from the initial high capital required for the R&D of automation.
- **Large to medium plants:** Due to the high R&D capital required to develop new automated systems, only large to medium plants can achieve the economies of scale necessary.
- **Full Automation:** Both technologies are considered because full automation are aimed at larger plants, while are aimed at smaller-sized plants.
- **Medium to low technology difficulty:** The cuts being automated in the first Horizon should include existing off-the-shelf technology and realistic expectations.

8.3.2 Cuts

For the first stage, it is important to gain confidence from the industry in demonstrating the commercial viability of integrating automation into beef processing. Therefore, the Horizon 1 of beef automation should focus on "low hanging fruit" solutions that are lower cost to implement, simple in operations, and have a strong return on investment. Technology such as automated beef scribing has already been pioneered by SAR and implemented with limited success.

According to lessons learned from lamb automation, the first stage of beef automation should focus on the most valuable cuts. Among the cuts that should be considered are the following.

- Standalone beef scriber to complete all vertical beef scribing cuts.
- Horizontal beef scribing cuts - Shoulder to Cube Roll & Cube roll to Striploin once the grading cut can be removed
- Chine Bone removal
- Integration of modules 1 & 2

8.4 Horizon II (2025-2030)

8.4.1 Assumptions

- **Medium value cuts:** After the higher-value cuts have achieved automation, technology price should have come down to allow automation for lower-value cuts.
- **Large, medium, small plants:** As beef automation technology matures, it should trickle down from large plants to smaller plants.
- **Medium technology difficulty:** The technology should be mature to tackle more difficult cuts.

8.4.2 Cuts

- Removal of ribs and feather bone from cube roll

The industry environment for the next 5 years is predicted to become more competitive, as international competitors such as Brazil and United States continue to catch up to Australia's quality and standards. However, Australia's wages are expected to increase further, prompting further erosion of competitive advantages. Thus, the automated solutions in the next five years should be focused on:

- Medium value cuts
- More difficult cuts
- More AI and machine learning driven automation
- More flexibility in cuts and the ability to change product specifications.
- More data capturing from automation and using data for decision-making.
- More trickle down of technology from large plants to medium and small plants.

As the price of technology drops, in the next five years, more ambitious automation projects involving more difficult cuts can be implemented. The Horizon II projects will be based on lessons learned and technology developed from the Horizon I projects. It is also essential for Horizon II modules to be backwards compatible with Horizon I modules, so that processors can theoretically integrate the automated modules with minimal compatibility issues.

8.5 Horizon III: Leg boning (2030 – 2035)

8.5.1 Assumptions:

- **Medium value cuts:** Horizon III should focus on the boning of the forequarter and hindquarter.
- **Large, medium, small plants:** This technology is suitable for plants of all sizes.
- **High technology difficulty:** The manual boning process requires a high level of dexterity, imaging technology, and artificial intelligence that will require long-term research and development to achieve commercialisation.

8.5.2 Cuts

- **Foreleg boning:** The foreleg may be removed as a whole or separated into various steps. The removal of the clot meat, chuck tender, tendons, and scapula bone could be automated.
- **Hind leg boning:** The hind leg boning automation may focus on the Silverside, Outside, Eye round, outside flat, as well as the thick flank, knuckle and topside.

The long-term “blue sky” project is the automation of the leg boning process. The key to the success of a boning system is the software system that must efficiently adapt to the specifications of each leg and execute the boning with the precision and speed of a human boner. Currently, the technical requirements and of boning a leg is impossible with any automated systems. In the LEAP II forequarter lamb automation trials, a robot boning prototype attached to a knife has already demonstrated the current technical limitations for full automation systems, which are not reliable or versatile enough for commercial use. However, in the next ten years, robotic and AI technology may become cheaper and powerful enough for an automated boning system. Therefore, it is important to be keenly aware of the development of robotic and AI technology, so the development timing of the automated leg boning process can be optimised.

9 Conclusion

As Australia's overall manufacturing industry declines further, Australian processors must begin to upgrade their knowledge and human resources in order to remain relevant in an increasingly data-driven and innovation-centric global marketplace. The cost of status-quo can mean a gradual recession of Australia's food manufacturing industry, as overseas processor competitors slowly nullify current Australian competitive advantages globally. This would result in more live exports and fewer domestic processing, as the costs of processing would become greater and greater.

The industry benefits of automation will not only be limited to monetary gains through cost-cutting and increase in efficiency. More importantly, lamb automation and beef automation also challenge the Australian red meat industry to become a global technological leader in meat processing technology. Companies such as SAR will be able to utilise the technical know-how gained in designing and implementing domestic automated systems to export to other markets around the world, thus creating a new industry driven by technology.

Currently, Australia is already the global leader in lamb automation technology. Therefore, it is a logical next step to extend the lead further into more challenging meat types, and cuts. The three Horizons strategy proposed by Greenleaf Enterprises can act as a macro-level blueprint in guiding industry towards beef automation, but the industry should be in no way limited to only these recommendations. The pace of innovation in manufacturing around the world, and the development of AI and machine learning technology have the potential to revolutionise red meat processing. Therefore, the Australian red meat industry must become more agile and innovative, and not become paralysed by inaction.

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11 Appendixes

11.1 List of Tables

11.2 List of Figures

11.3 Previous Work

Previous beef and lamb automated systems developed by SAR are compiled to provide an empirical overview of current existing automation capabilities by an industry leading provider of automation technology (Table 15)

Table 15: Automated systems developed by SAR

Type of Technology	Description
Beef Rib Cutter/Scriber	SAR understands that scribing is the first point at which yield can be lost during the boning process of beef.
Robotic Forequarter Sani Vac	The Robotic Forequarter Sani Vac by SAR is an automatic steam vacuum that replaces manual leg, neck, and brisket steam vacuum sanitisation for meat processing.
Knuckle Tipper	The Automated Knuckle Tipper replaces the unsafe process of removing knuckles with bandsaws. The unit's geometry optimises the cut location to maximise yield.
Beef Boning Unit	SAR have designed and manufactured a world class beef boning unit with a manual-assist mechanical arm.
Striploin Saw	SAR Striploin Saws are specially designed with a sliding table, angled blade, laser guides, control handles, and an emergency stop in order to deliver the safest and most efficient means of removing the striploin from the chine bone.
Forequarter System	SAR forequarter systems use a 3D vision camera to scan each forequarter, creating a virtual model and the optimal cut locations which guide a robotic arm that grasps the forequarter and uses a bandsaw to make the cuts. The forequarter products are then transferred to a conveyor belt for further processing and final packaging.
Beef Hock Cutter	The Robotic Beef Hock/Hoof Cutter replaces the manual hock cutting operations for beef processing. This beef technology solution utilises a robot with integrated sensing to profile, detect and accurately cut the hock.
Automated Boning Room	SAR Boning Room Systems were designed to optimise yield, minimise waste, increase food safety and reduce operational costs. The automated boning room is a fully automated system for processing "bone-in" meat products and is able to process carcasses at a rate of 12 per minute.
Standalone Chine	The SAR Lamb Chining machine is designed to safely remove the chine from rack saddles using proprietary 'Chine Rider' technology, resulting in a top-quality product with a high yield.

X-Ray Imaging System, LEAP III, IV, V	The patented x-ray system is designed to determine the skeletal structure of a carcass and determine the ideal cut points for separation of the Forequarter, Middle and Hindquarter.
Robotic Hindquarter Sani Vac	The Robotic Hindquarter Sani Vac by SAR and Robotics is an automatic steam vacuum that replaces manual steam vacuum sanitisation for lamb, sheep and goat processing.
Kidney Fat Removal	The Robotic Kidney Fat Removal system by SAR replaces the manual kidney fat removal process for smallstock, lamb and sheep processing.
DEXA	DEXA (Dual Energy X-Ray Absorptiometry) Objective Carcass Measurement provides a measurement of lamb carcass composition is used to provide a measure of lean, fat and bone ratio for each product. DEXA has been used for decades in the medical industry to measure bone density and body fat composition. In the red meat industry, DEXA technology provides timely, accurate, transparent and objective information on the lean meat, bone and fat composition of each carcass.

11.4 History of Lamb Automation

The timetable shows the entire history of lamb automation, the timeline of the various projects, and the phases of implementation. The implementation phases were broken into five LEAPs, with overlapping and parallel development of multiple LEAPs at the same time (Figure 2).

11.4.1 Leap II: Hindquarter boning for lamb

The LEAP II system by SAR/RTL Lamb boning system development was a hindquarter boning system developed with an industry robotic arm attached to a knife. A prototype was developed by SAR. However, the technology was not efficient enough for commercialisation. Therefore, The LEAP II system ceased development (MLA 2018).

11.4.2 LEAP III: Primal cutter and x-ray visioning

LEAP III is an automated lamb primal cutting system paired with x-ray imaging technology. The imaging system is designed to identify the optimum cutting lines, while the automated cutting system clamps down the carcase and breaks it into forequarter, middle and hindquarter sections (MLA 2018). This system is designed to integrate with LEAP IV and V modules.

The first prototype was introduced in 2006 and retired in 2009. Several problems from the prototype were identified. These problems allowed SAR to perfect the technology for subsequent installations with an improved x-ray imaging system. LEAP III was first installed in 2011 at the Australian Lamb Company with a full x-ray imaging system. Subsequently, JBS, Colac and other facilities adopted the LEAP III system for industrial processing. The system has also been successfully integrated with LEAP IV modules.

11.4.3 LEAP IV: Lamb middle cutting machine - splitting, flap cutting, rack & loin separation, spine cord removal modules

The LEAP IV system is an automated lamb middle cutting system with assistance from a camera. The system is designed to break the rack barrel into various sub-primal parts, with an optional chining module. SAR was in charge of the development of LEAP IV, and a system consisting of an x-ray, primal and middle process was successfully installed and operated in JBS in 2014, and ALC in 2015. The technology is currently suitable for commercial implementations (MLA 2018).

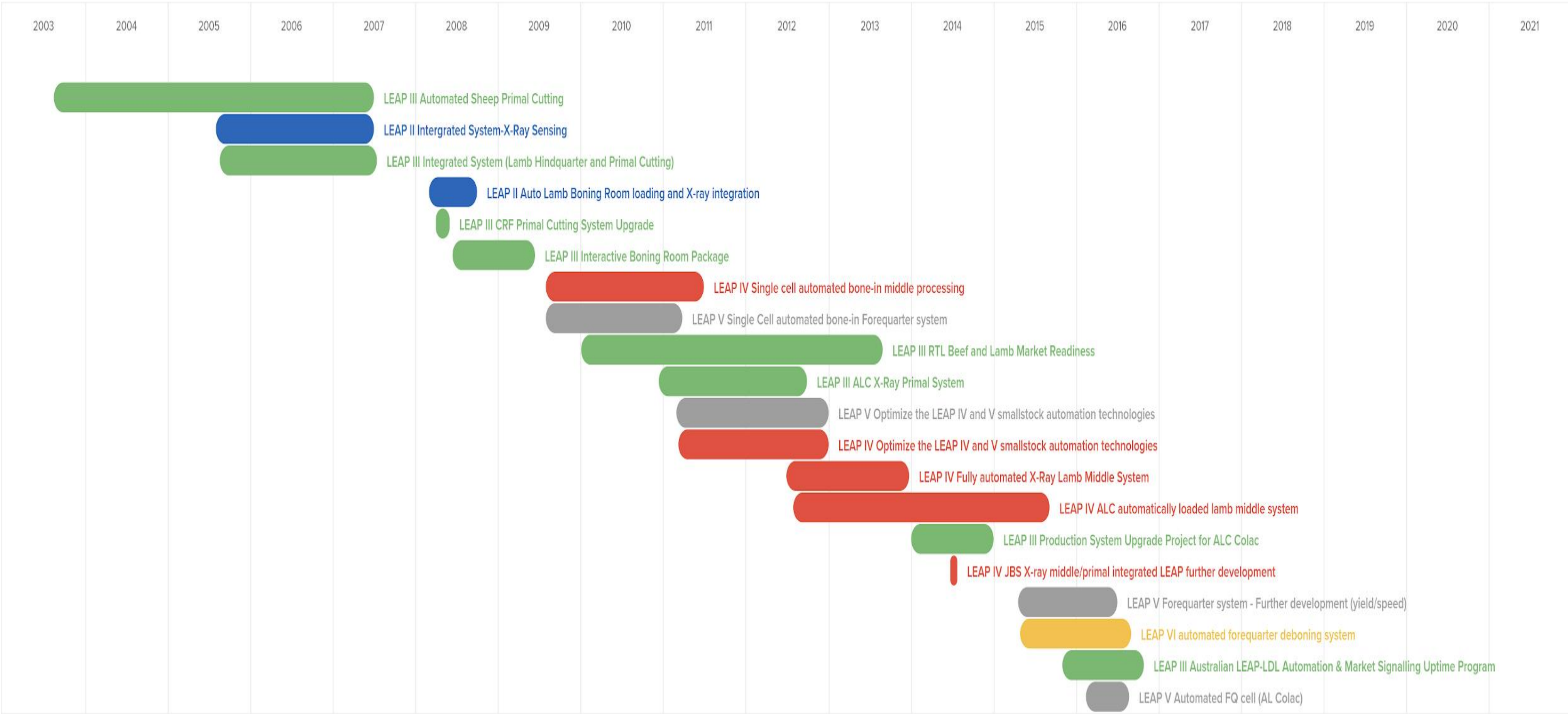

Figure 45: History of Lamb Automation

11.4.4 LEAP V: Forequarter ovine cutting (bone in)

The LEAP V forequarter cutting system is designed to separate the neck, the shank and splitting to produce the square cut shoulder portions using a series of robotic servo-controlled bandsaws. This has increased the consistency of product output, increased OH&S, and labour benefits. Currently, the main functions of the system include knuckle tip removal, neck cuts, shank and brisket removal and vertebrae splitting (MLA 2018). A few systems have been implemented in commercial settings with limited success.

11.4.5 LEAP VI automated forequarter deboning system – Stage 1 concept development

The LEAP VI system is envisioned to be an automated boning system for lamb forequarters. Currently, the system is being reviewed, with two concepts being developed. However, prototypes are yet to be made (MLA 2018).

Table 16: LEAP System History

LEAP System	Title	Start Date	End Date
LEAP II	Auto Lamb Boning Room loading and x-ray integration	1/3/08	1/10/08
LEAP II	Leap 2&3 Integrated System and x-ray Sensing	1/8/05	30/6/07
LEAP III	Leap 3 - Automated Sheep Primal Cutting	15/8/03	30/6/07
LEAP III	Leap 2 and Leap 3 Integrated System (Lamb Hindquarter and Primal Cutting)	20/8/05	15/7/07
LEAP III	RTL Beef and Lamb Market Readiness	5/1/10	29/8/13
LEAP III	Leap Animation - Interactive Boning Room Package	15/6/08	15/6/09
LEAP III	Leap III - CRF Primal Cutting System Upgrade	1/4/08	30/5/08
LEAP III	ALC Colac LEAP III Production System Upgrade Project	1/1/14	12/11/15
LEAP III	ALC X-Ray Primal System	15/12/10	30/9/12
LEAP III	Australian LEAP-LDL Automation & Market Signalling Uptime Program	1/11/15	26/10/16
LEAP IV	LEAP IV Single cell automated bone-in middle processing	1/8/09	30/6/11
LEAP IV	JBS X-ray middle/primal integrated LEAP further development	27/6/14	25/7/14
LEAP IV	Optimize the LEAP IV and V smallstock automation technologies	1/3/11	31/12/12

LEAP IV	LEAP IV – ALC automatically loaded lamb middle system	1/8/12	7/9/15
LEAP IV	Fully automated x-ray Lamb Middle System	1/7/12	23/12/13
LEAP V	Optimize the LEAP IV and V smallstock automation technologies	1/3/11	31/12/12
LEAP V	LEAP V Single Cell automated bone-in Forequarter system	1/8/09	25/3/11
LEAP V	Leap V Forequarter system - Further development (yield/speed)	20/4/15	30/6/16
LEAP V	Automated FQ cell (AL Colac)	15/2/16	23/8/16
LEAP VI	LEAP VI automated forequarter deboning system – Stage 1 concept development	1/5/15	2/9/16

11.4.6 **Lessons learned from lamb automation**

LEAP II system was over ambitious trying to tackle a highly technical problem of boning the leg, which to this day poses great technical challenges. LEAP II never advanced beyond prototype stage due to severe technical and reliability constraints.

LEAP III focused on breaking down the primal into forequarter, middle and hindquarter sections with the aid of x-ray imaging. This was much easier to implement due to the simple sawing motions, that did not require boning or other complicated processes. It also allowed LEAP III to be integrated with LEAP IV and V technologies focusing on sub-primal cuts.

The LEAP IV targeted the sub-primal cuts of the middle section, which consisted of the most valuable cuts. The LEAP IV also generated the most return on investment compared to other systems, which is also the most widely adopted system.

The LEAP V forequarter cutting system was designed to separate the neck, the shank and splitting to produce the square cut shoulder portions using a series of robotic servo-controlled bandsaws. However, the adoption rate is not as great due to lower return on investments.

LEAP VI is similar to LEAP II because it attempts to automate the boning of the forequarter. However, the project has not moved beyond the conception stage.

11.4.7 **Semi automated aitch bone (cut 9) & knuckle removal**

11.4.7.1 Aitch bone removal

The accuracy of cut 9 was largely determined by the location of the cut through the following anatomical structures seen in Figure:

1. The lymph node;
2. The aitch bone to the cranial end of the femur and hip bone joint;

3. The cartilage tip;

Figure 46: Ideal location of the cut 9.

The table boning method for separating the leg primals at the Wagga plant differs from the other plants that chain bone using a SAR aitch bone puller system. Boning method contributes to yield of leg primals as much as Cut 9 band saw accuracy. Managers believe the table boning method is not removing as much of the meat from the aitch bone as the beef puller.

The SAR beef puller was designed for the removal of aitch bones and knuckles from the hindquarter. It consists of an overhead mounted pneumatic ram with a connected arm that has 2 horizontal pivot points (**Figure 46**). Boners place the hook on the aitch bone, and use a finger control to activate the ram and provide a controlled downward force on the aitch bone as it is pulls away from the hindquarter while marking with a knife in the other hand.

Use of this commercially available system will eliminate the need for cut 9 and also reduce the OH & S risks associated with hindquarter boning.

Figure 46: An aitch bone pulling being used

11.4.7.2 Knuckle removal

Traditionally the knuckle primal is removed from the hind quarter, pulling down with a hook in one hand from the distal end and seaming between muscle primals either side with a knife in the other hand. The pulling of the knuckle away from the femur bone and other muscle primals does require a fair amount of force and over the period of a shift is generally considered to be physically demanding.

The plant has developed an in-house system with the use of a pneumatic ram under the stand, and a chain (with a hook), connected to an overhead counter balance mounted on a roller, allowing the upper part of the puller to move with the chain. The operator inserts the hook into the knuckle as they would manually, then activates the ram by a pneumatic trigger on the hand piece pulling the hook down with the knuckle attached.

The SAR beef puller can also be used as a knuckle puller to replace the above and would be paired with a similar beef puller for aitch bone removal.

11.4.7.3 Primals affected

There are a number of cuts affected by boning variation. The primal and the associated yield losses can be seen in Table 17.

In circumstances where the cut is moved in the caudal direction the cut increased the amount of silverside on the rump and increased the amount of knuckle sold as trim. The variation shown by this cut is minimal as 95% of the samples recorded were ±10mm from the ideal location of the cut.

Table 17: Source of yield loss for hind quarter muscle primals, caused by the variation cut 9

Primal	Location of boning loss	
Rump	Aitch Bone Top Side Trim	Knuckle Silverside
Knuckle	Rump Top Side	Silver Side Trim
Top Side	Aitch Bone Knuckle	Silverside Trim
Silver Side	Knuckle	Top Side
Tenderloin	Aitch Bone	
Shin	Silverside	