Final report

Lamb DEXA grading with producer feedback, Value Chain integrated system to deliver the JBS "Buy/Make/Sell" Strategy

Project code: P.PIP.0466

Prepared by: Sean Starling
JBS Australia Pty Ltd

Date published: 15 February, 2022

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

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

Abstract

JBS and MLA engaged Scott Automation and Robotics to install an improved and advanced DEXA enabled lamb primal cutting and middle processing cells. In addition to advancements in the DEXA Primal and Middle processing machines previously developed by Scott, the middle machine also had the inclusion of a new to be developed "sticky-rib" and loin deboning machine modules, and allow for a pending waterless Frenching solution. In addition to these new modules, this installation would also include the world's first 10 cpm forequarter square cut processing cells (comprising of three integrated robotics cells, enabled by 3D profiling scanners).

The inherent sensing in the process, including DEXA, would enable reporting benefits through the JBS "Buy/Make/Sell" business model.

The Primal and Middle machine was recreated from the knowledge of previous projects with responses to the previous learnings incorporated, including design changes (direction of product flow and integration) to accommodate the specifics of the available room layout. The middle machine successfully had incorporated the "stick-rib' cutting module.

At the conclusion of the project the DEXA, primal cutter, and standard module middle machine are functioning to specification from a processing automation perspective.

The forequarter processing cell and its integration was new and involved a concepting, prototyping and testing phase before designing and building a production suitable machine. At the conclusion of the project

At the conclusion of the project the forequarter cells are operational and are producing a minimum viable product from a processing uptime perspective, however JBS and Scott continue to investigate ways to increase the uptime.

The Loin Deboner development was novel because of the requirement to separate meat from bone with very demanding yield specifications. Therefore, a significant concepting and prototyping was deployed throughout the project, including the last further development phase.

At the conclusion of the project the loin module is still not finalised and it is unknown if the design will ultimately process Australian specification (size) lamb. JBS and Scott will continue to develop this module with an aim to integrated it into the system at a later date. The unit will be installed during the 2022 Christmas / NYE shutdown period.

The DEXA system is commissioned and outputting data.

At the conclusion of the project the DEXA output is currently not a level that can reliably be used to inform producers. In addition to this RFID enabled skids are still a barrier to provide carcase by carcase feedback to producers. JBS will continue to work with Scott, Murdoch Uni and RFID providers to address both limitations here and then commence producer feedback and engagement activities, once the data is proven reliable and robust.

Although the project has not achieved all of its original objectives, the platform installed will enable JBS to deliver the original outcomes, with an aim to conclude this by the end of 2022. JBS will continue to work with MLA, Scott, Murdoch and RFID providers to conclude the original project Vision. Once the DEXA output (for supply chain, not automation) is functioning correctly, and an RFID gambrel solution is robustly installed, JBS will be able to undertake producer engagement activities, including holding open days to demonstrate to producer suppliers how the slaughter to boning traceability functions and then how the DEXA unit providers their feedback, enabled by the traceability.

Note: MLA acknowledges that some delays occurred due to COVID-19 impacts on Australian meat processors and wider supply chains. This required JBS and Scotts to remain very agile in the design and delivery of this work against initial plans.

Executive summary

Background

The research target is to support the integration of the whole of supply chain initiative and deliver traceable lamb products.

The output of real time sensing, with inclusion of the likes of Dual Energy X-ray (DEXA) enables supporting MLA objective carcass measurement and direct data communication initiatives. There is an opportunity to use the carcass measuring data to drive process settings for product optimisation.

Exploitation of objective carcass data and the product traceability is proposed to increase producer returns through JBS's current and future "Lamb Value Chain Strategy" all the value chain participants.

The feedback systems and traceability should enable capturing market intelligence and producer value-based payment systems.

The integration of the processing system has identified the benefit of adding short rib, forequarter processing and loin deboning modules.

The target audience is to benefit the Australian red meat industry, across the entire value chain.

The results of the research will support the evolution of the automation components in future processor automation installations which will further enable the tailoring of processing and feedback systems.

Objectives

The objective of the project was;

1. Designed, developed, installed and commissioned a radio-frequency identification RFID enabled (not achieved) dual energy x-ray carcase system (DEXA) that will not only be used to drive the forequarter (bone-in and bone-less) processing cell, and ascertain which carcasses should be processed with the new "sticky rib" middle cutting module (achieved), but will also provide producer feedback on lean meat yield of their livestock provided by JBS (not achieved).
2. Re-designed, developed, installed, and commissioned a bone-in 10 carcasses per minute square-cut forequarter processing system. (achieved)
3. Designed, developed, installed, and commissioned a new "sticky rib" cutting module that will be integrated into the existing (albeit modified) middle machine. (achieved)
4. Completed producer feedback, engagement, and training, to realise a value-based trading system for lamb. (not achieved)
5. Developed JBS producer network, JBS producer groups, PDS programs connected to the network. (not achieved)
6. Undertaken industry open days, and producer education days. (not achieved)
7. Developed a post installation cost benefit analysis and dissemination video and report. (achieved, excluding producer feedback and loin module inclusions)

The targeted benefits were:

- Allows red meat companies to move towards Value based grid / payment system
- Facilities improved productivity on farm through enhanced feedback.

- Higher rewards for better performance
- Build grids based on LMY with value chain win / win = increased returns
- Animal health gains, reports on for instance: seeds and offal condemn
- Targeting specific markets based on carcase attributes
- More consistent product to process

Methodology

The Primal and Middle machine was recreated from the knowledge of previous projects and with the inclusion of responses to the previous learnings. Issues were identified through the commissioning and tuning phase with various developments implemented to achieve the accuracy and uptime requirements.

The forequarter processing machine and its integration was new and involved a concepting, prototyping and testing phase, before designing and building a production suitable machine. Then a tuning and refinement phase was performed at the processors site.

The Loin Deboner development was novel because of the requirement to separate meat from bone with very demanding yield specifications. Therefore, significant concepting and prototyping was deployed throughout the project, including the last further development phase. This module is still undergoing further developments.

Results/key findings

Many of the issues that were experienced were both not foreseen and resulting from inputs or environment that the equipment has not faced in previous installations.

Carcase transfer and integration has provided several key learnings regarding the setup and installation approach for future installations. Measurement methodology used to benchmark machine cut accuracy has been significantly improved. Carcase skid, gambrel movement and carcase stability during the transfer processes across integration points proved to be a key hurdle in initial commissioning stages.

It was found that input carcase quality had a profound effect on the performance of the system (as it also would with manual cutting). Having the DEXA, Primal and Middle system in place has assisted JBS to identify upstream carcase processing issues readily and address them on a timely basis which further adds benefit from the system to JBS business.

Onsite maintenance was shown to be critical for items such as camera cleaning and checking setups. Complex systems, like these systems, do require comprehensive diagnostics to enable responding to failures in a timely manner with the onsite front line generalist support staff.

The loin deboning process has presented significant challenges to achieve the processor requirements regarding refinement of the removal of product from the skeleton. The viability of the new machine is measured by the yield exceeding current means of boning, such as the BLM machine for eye of loin removal and manual tenderloin removal. These developments are still underway at the time of writing this final report.

The development reaffirmed the difficulty of separating meat product from the skeleton with a yield higher than the current mature processes. The development also highlighted the impact of product variation, even between New Zealand and Australian processors.

Trials on the processors site were performed in milestone 15 and 16 which identified shortcomings regarding required yield and uptime. A subsequent milestone, milestone 31a, was added to further develop the Loin Deboner and address the shortcomings. Various inventions and developments have been applied, yet an acceptable solution design, from an output perspective, has not be achieved to date.

With the further developments the Loin Deboner process has been assessed, with trials in the SCOTT factory, as removing tenderloins and eye of loins as per the requirements established.

Quantitative validation of the yield and uptime has not been possible to date on a processor site or on processor quantities due to COVID travel limitations.

Benefits to industry

The outcome of the project has demonstrated the capability of fully automated and integrated primal cutting, processing of the lamb middles and forequarter processing.

The DEXA data enables the wider project objectives to leverage benefits through the JBS "Buy/Make/Sell" business model.

The ability to perform a second cut on larger carcasses and create a short rib product increases the value from the carcass.

The results from the factory testing of the Loin Deboner, after the further development phase, indicate the achievability of a commercial standalone machine that will deliver yield and labour saving. Additionally, once mature, the loin deboning system could be integrated into the SCOTT middle machine.

Future research and recommendations

It is anticipated that the issues and learnings from this research will further improve future installations by ensuring that correct mitigation can be put in place at the time of installation or during the machine build.

Further research opportunities include:

- Further development of carcass stability and X-Ray scanning accuracy
- Application of 3D vision systems for the likes of rib length determination
- Enhanced accuracy both for X-Ray analysis and rib length determination
- Use of DEXA data for value-add opportunities

Table of contents

Abstract **2**

Executive summary **4**

1. Background **10**

1.1 DEXA Primal, middle and forequarter processing machines **10**

1.2 Loin Deboner system development **11**

2. Objectives **12**

3. Methodology **13**

3.1 Primal, Middle and Forequarter processing machine development13

3.2 Loin Deboning processing machine development **14**

3.2.1 Design and development process included 14

3.2.2 At processor site trials 14

4. Results **16**

4.1 Primal, Middle and Forequarter processing machines **16**

4.2 Loin Deboner processing machine development **24**

4.2.1 Overall 24

4.2.2 Loading 25

4.2.3 Tenderloin removal station 26

4.2.4 Eye of loin removal station 27

4.2.5 Process product Results **29**

4.2.6 Qualitative yield assessment 29

4.2.6.1 Loading 29

4.2.6.2 Tenderloin removal 29

4.2.6.3 Eye of loin removal 30

4.2.7 Trial 145 example 30

4.2.8 Machine performance 31

4.2.9 Integration into SCOTT lamb middle processing machine 31

4.2.10 Business case review 31

5. Conclusion. 32

5.1 Primal and Middle machine 32

5.1.1 Key findings 32

5.1.2 Benefits to industry 32

5.2 Loin Deboner processing machine development 33

5.2.1 Key findings 33

5.2.2 Benefits to industry 33

6. Future research and recommendations 34

6.1 Primal, Middle and Forequarter processing machines 34

6.2 Loin Deboner 34

7. References 35

8. Appendix 35

8.1 Milestone 31a Loin Deboner processing machine further development 35

8.1.1 Milestone 31a objectives 35

8.1.2 Overall 35

8.1.3 Loading 36

8.1.3.1 Enhancement to the loading, location, and spine scraping 36

8.1.4 Tenderloin removal station 39

8.1.4.1 Tenderloin removal 39

8.1.5 Tenderloin tail cutting process 41

8.1.6 Eye of loin removal station 42

8.1.6.1 Carriage clamp enhancement 42

8.1.6.2 Fixed blades automatic height adjustment. 44

8.1.6.3 Feather bone/button bone yield 45

8.1.6.4 Eye of loin removal from the extremity of the transverse processes 47

8.1.7 Process product Results 48

8.1.7.1 Trial 145 48

8.1.7.2 Trial 147 49

8.1.7.3 Trial 150 50

8.1.7.4 Trial 154 51

8.1.8 Summary of machine performance 52
8.1.8.1 Qualitative yield assessment 52
8.1.8.1.1 Loading 52
8.1.8.1.2 Tenderloin removal 52
8.1.8.1.3 Eye of loin removal 52
8.1.8.2 Machine performance 52

1. Background

1.1 DEXA Primal, middle and forequarter processing machines

For the past fifteen years Scott Automation and Robotics (SAR) in partnership with Meat and Livestock Australia (MLA), Silverfern Farms and supported by various Australian processors have been developing their vision of a fully automated bone-in lamb processing concept known as LEAP. The first four components of the vision include x-ray sensing, Primal cutting, Middle cutting, and Forequarter bone-in cutting systems. The X-ray, Primal and Middle modules are installed and operational in several Australian processing facilities operating up to 10cpm whilst the Forequarter module is yet to be integrated into a system at 10cpm. Additionally, there are a series of Middle tasks yet to be developed and integrated into the Middle module at 10cpm and the DEXA is yet to be integrated into an Australian facility with the ability to measure carcase meat yield traits and have the data available to the producer suppliers on a per carcase basis.

Traditionally the LEAP system was designed to operate with single energy x-ray absorptiometry (SEXA) sensing which can differentiate the skeletal anatomy of each carcase from its surrounding tissue using a bifocal methodology (pseudo 3D). This technique enabled key bone related landmarks to be identified and 3D data co-ordinates to be generated to drive a series of cutting modules that can accurately, efficiently, and repeatedly dis-assemble carcases on their individual geometric cut lines.

With the implementation of the LEAP systems into various processing plants including some of the flagship Silverfern farms plants it was soon identified that carcase measurements that could be extracted from the x-ray system were of significant benefit to the producer engagement process and in ensuring yield was a focus of delivery within the value chain network. Initial work was completed to use the x-ray system to determine weights of primal segments and sizes of products and this data was used to drive producer engagement. It was found in a relatively short period of time that livestock supply reacted to the feedback being supplied and that carcase deliveries to the plant trended with higher primal weights for target areas. However, it soon became apparent that weight did not directly correlate to yield as much of the weight was being delivered as fat. It was at this point that Scott and Silverfern farms did an initial investigation into the use of dual energy x-ray absorptiometry (DEXA) to measure meat yield as opposed to weights alone. Initial work was undertaken, and it was shown that the DEXA to be an effective tool in measuring meat yield based on a small scale experiment conducted in New Zealand that correlated the result to a measurement by CT. Since that evaluation, Scott, MLA, and industry partners with assistance from Murdoch University have completed the validation of DEXA to prove the accuracy on Australian flock variations and verify the algorithm for commercial use within Australia (validated by Murdoch University). This is operational in the pilot Australian plant for chilled lamb carcases only at this stage and is not traceable per carcase back to producer handover of livestock.

The work done proved the use of DEXA as a direct measurement of Lean Meat Yield of a carcase when used on either hot or chilled bodies.

Recently independent studies have been performed to determine the benefits of this technology to industry and it has been found that AUD420M of benefit is unrealised within the Australian red meat industry.

Benefits are derived from a variety of yield measurement applications. Some of the major benefits that can be quantified include its use to drive breeding decisions, its use to underpin processing decisions, the analysis of yield recovery and continuous improvement of carcase disassembly and the ability to drive efficiency and accuracy through the automation of carcase cutting. Other benefits will also stem from the use of yield measurement within the meat industry including potentially increased consumer demand because of standardisation of product, the ability to improve on-farm practises to improve efficiencies, the ability to streamline inventory management and the ability to underpin quality assurance programs to name a few.

JBS Australia is the largest red meat protein manufacturer in Australia with Beef and lamb processing located up and down the east coast. JBS have a well-established business model termed the "buy, make sell" model which comprises a strong producer engagement process as well as a strong focus on each of the key stages in the overall value chain being the production on farm, the efficient processing and dis-assembly and the presentation to consumer. This business model put JBS in a unique position to implement and evaluate the capability of DEXA meat yield measurement to return value to each of the key stages in the value chain.

This project "*Lamb DEXA grading with producer feedback, Value Chain Integrated system to deliver the JBS "Buy/Make/Sell" Strategy*" is designed to implement the DEXA and LEAP systems into JBS Brooklyn to demonstrate and measure as many of the key benefits attainable from the DEXA lean meat yield measurement technology as possible. To achieve this overarching goal, this project also acts as a platform for the integration of the fourth LEAP module (Forequarter bone in module) including refinement to expand its capability to process Australian carcase variations and product specifications.

The benefits of including a 'short rib' and loin deboning system into the middle machine was identified. With the view to leverage of the DEXA-LEAP system on Australian carcases.

1.2 Loin Deboner system development

The Loin Deboner development is a component of automating the lamb boning processes. The research in this project is part of the journey for the integration of an automated Loin Deboner system into the SCOTT middle machine.

The current boning room solution is typically the utilisation of the BLM machine for the eye of loin removal and a manual process for the tenderloin removal.

This research targets performing both eye of loin removal and tenderloin removal in the same station.

From processor feedback the requirements have been determined as:

- Both tenderloin and eye of loin removal in a single machine

- Processing rate of 10 products per minute.
- Enhanced yield, tenderloin removal, relative to the manual process.
- Enhance yield, eye of loin removal, relative to current available machines.
- Labour savings from the increased rate and automated unloading.
- Process reliability. Target of 98% uptime.
- Health & safety equivalent or improvement
- Reduced machine footprint dimensions, for the equivalent processing capability.

Current meat processing developments, performed by SCOTT, are typically cutting with enhanced precision, the Loin Deboning development is fundamentally a separation of the meat product from the bone. This is a new development and unknown in the industry. The yield requirements add significantly to the challenge.

It was determined, with stakeholder engagement, that the loin deboning system development would be most effectively performed with a standalone machine. Once the standalone machine is mature, the process could be integrated into the SCOTT middle machine.

The evaluation of the latest loin machine developments have been hampered by COVID restrictions not enabling either JBS to get to New Zealand to review, or Scott New Zealand designers/engineers to come to Australian and evaluate within the JBS Brooklyn facility. Once COVID restrictions ease, this development will recommence.

2. Objectives

At the conclusion of the project, MLA, JBS and Scott will have:

1. Designed, developed, installed and commissioned an radio-frequency identification RFID enabled dual energy x-ray carcase system (DEXA) that will not only be used to drive the forequarter (bone-in and bone-less) processing cell, and ascertain which carcasses should be processed with the new "sticky rib" middle cutting module, but will also provide producer feedback on lean meat yield of their livestock provided by JBS.
2. Re-designed, developed, installed, and commissioned a bone-in 10 carcasses per minute square-cut forequarter processing system.
3. Designed, developed, installed, and commissioned a new "sticky rib" cutting module that will be integrated into the existing (albeit modified) middle machine.
4. Completed producer feedback, engagement, and training, in order to realise a value-based trading system for lamb.
5. Developed JBS producer network, JBS producer groups, PDS programs connected to the network.
6. Undertaken industry open days, and producer education days.
7. Developed a post installation cost benefit analysis and dissemination video and report.

Additional details

Benefits

The expected benefits are:

- Allows red meat companies to move towards Value based grid / payment system
- Facilities improved productivity on farm through enhanced feedback
- Higher rewards for better performance

- Build grids based on LMY with value chain win / win = increased returns
- Animal health gains, reports on for instance: seeds and offal condemn
- Targeting specific markets based on carcase attributes
- More consistent product to process

3. Methodology

3.1 Primal, Middle and Forequarter processing machine development

The overall design of integrating the Primal, Middle and Forequarter processing systems into the JBS plant was undertaken collaboratively with a master AutoCAD layout. Both JBS and SCOTT were able to draw on learnings from previous similar installs.

The overall site design involved considerable identification of plant floor loads and services requirements. Collaboration was performed between the JBS consultants, SCOTT, and other contractors.

The Primal and Middle machines were largely developed in previous projects, but previous learnings were responded to. And new developments incorporated, including the DEXA X-Ray and short rib module.

The 10 carcasses per minute integrated forequarter processing system was new. Some learnings were available from the previous project. Key high-risk areas related to the process were identified, prototyped, and trailed inhouse at the SCOTT factory. These areas include:

- Three sick ruler scanners
- Product Lifters and conveying on cut surface
- Product orientation vision system & analysis software

The forequarter processing machine development involved developing concepts, establishing evaluation models, and then evaluating the concepts.

The machine is designed utilising SCOTT experts and modelled in 3D CAD.

The Primal, Middle and Forequarter processing machines were all built and fully assembled and commissioned in the SCOTT factory.

A factory acceptance test was performed with the processing of 80 products demonstrated.

The system was then containerised and shipped to JBS Brooklyn plant.

The systems were installed in the JBS Brooklyn plant with SCOTT and SCOTT supervised contractors.

The machines were dry commissioned as per factory performance then product introduced and machine performance and cut accuracy monitored.

Various issues were identified and worked through with significant problem-solving tools and monitoring employed.

The tools included:

- Carcass stability measuring tool
- Chain and imaging system tracking analysis

- 3D reconstruction trials and visualisation tools
- X-Ray scanning calibration tools
- Reporting of all performance parameters – including accuracies, uptime and production rate/processed numbers
- X-Ray shielding simulation and measuring

Response to some issues necessitated significant developments. They included:

- Co-Planar X-Ray scanning development
- Infeed conveyor control program
- New X-Ray scanning test fixture
- Rack loin cut determination with CNN strategy
- Rib length vision system upgrade

3.2 Loin Deboning processing machine development

3.2.1 Design and development process included

- Analysis of the high-speed video to establish the root causes for each of the performance shortcomings.
- Scientific process for concept creation and development with the utilisation of SCOTT specialists and processor collaboration.
- Design of a prototype for concept validation with 3D CAD
- Building of the prototype for bench testing and/or incorporation into the machine. Including 3D printing, water jet cutting and conventional manufacture methods.
- Trials with the prototype. Where loins were supplied from a local processor, kept essentially in the cool chain, and then run in the SCOTT factory.
- Video and photographic recording of the process and trial outcomes.
- Evaluation of the trial outcomes. Where the product variation, and its theoretical impact on the process is included into the evaluation.
    - The tenderloin removal process was evaluated qualitatively by assessing the quantity of tenderloin remaining on the bone.
    - The eye of loin was also evaluated qualitatively by assessing the quantity of eye of loin remaining on the bone. Additionally, the quantity of bone that was removed and transferred to the product was assessed.
- Iteration of the above methods.

3.2.2 At processor site trials

- All trials were in the SCOTT factory

Figure 1: Photos show some of the "prototypes" that have been created

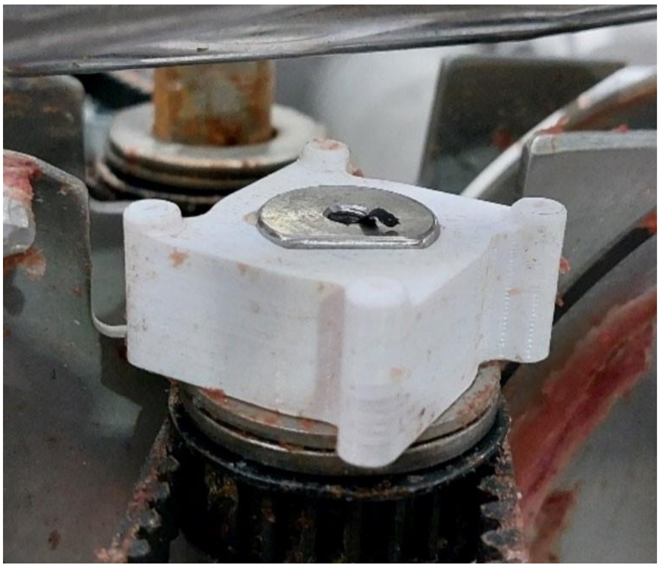


Figure 2: An example of one of the versions of TL removal wheel that was 3D printed

4. Results

4.1 Primal, Middle and Forequarter processing machines

The wet commissioning extended out for a longer duration that initially anticipated due to unforeseen hurdles and issues.

Client requirements were established inline with expectations set from other similar installations.

The key performance parameters were monitored and reported.

The outcome of the responses to the shortcomings was that the machines passed the acceptance criteria. The key performance parameters included rate, uptime, and accuracy of all cuts.

The developments performed to achieve required deliverables included:

- Co-Planar X-Ray scanning system to increase accuracy of the X-Ray scanning by providing significant improvement in immunity to carcass instability.
- Infeed conveyor control program to provide robust synchronisation of overhead chain conveyors to satisfy the controlled movement through the scanning system.
- New X-Ray scanning test fixture to enhance X-Ray calibration and associated accuracy.
- Rack loin cut determination with CNN strategy to enhance rack loin cut position determination.
- Rib length vision system upgrade for the flap cut.

At the time forequarters with a bend neck were excluded with an exception.

The machines are in full production, operated and the first line of support provided by JBS staff. SCOTT is engaged as required for the likes of servicing or significant support requirements.

The overall system delivered is shown in the following figures.

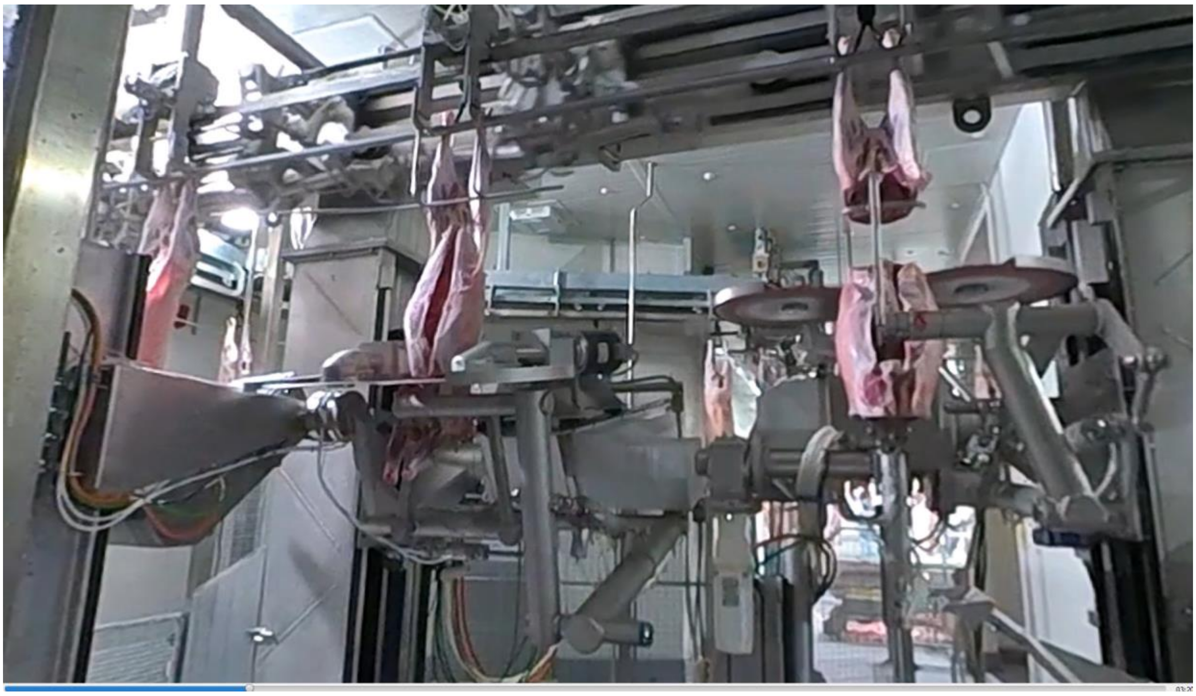


Figure 3: Primal Machine

Figure 4: Integration from Primal to Middle and Middle Infeed

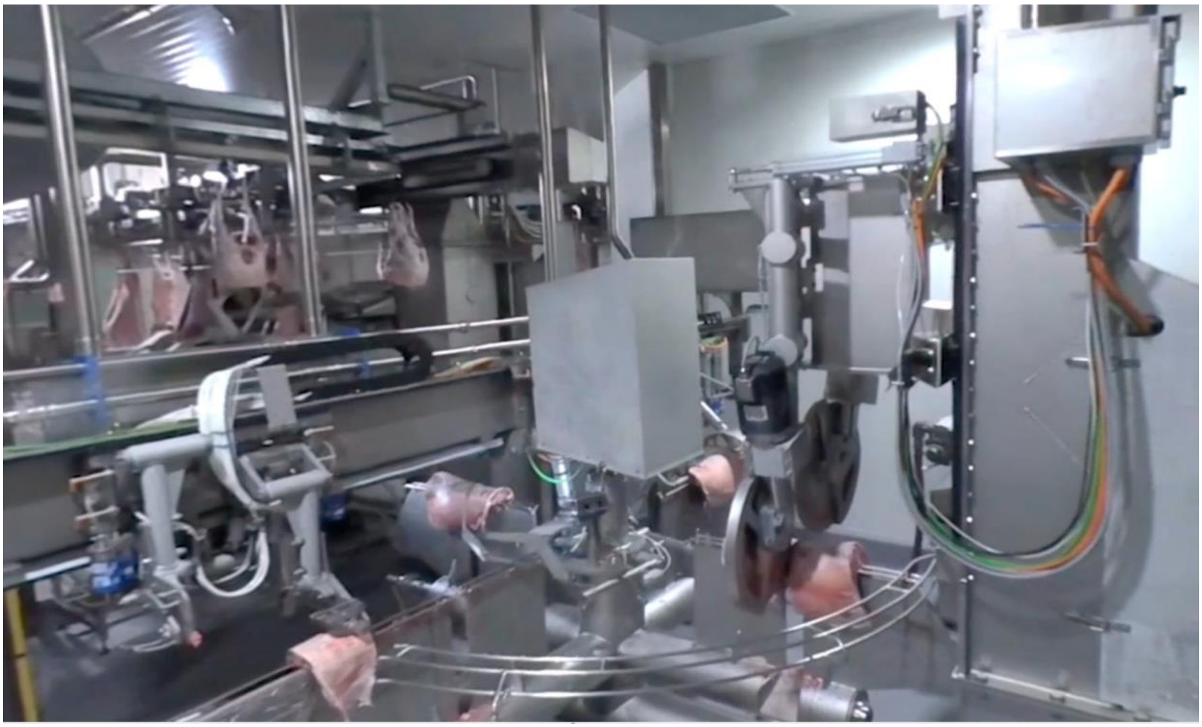


Figure 5: Middle machine rotary transfer stations

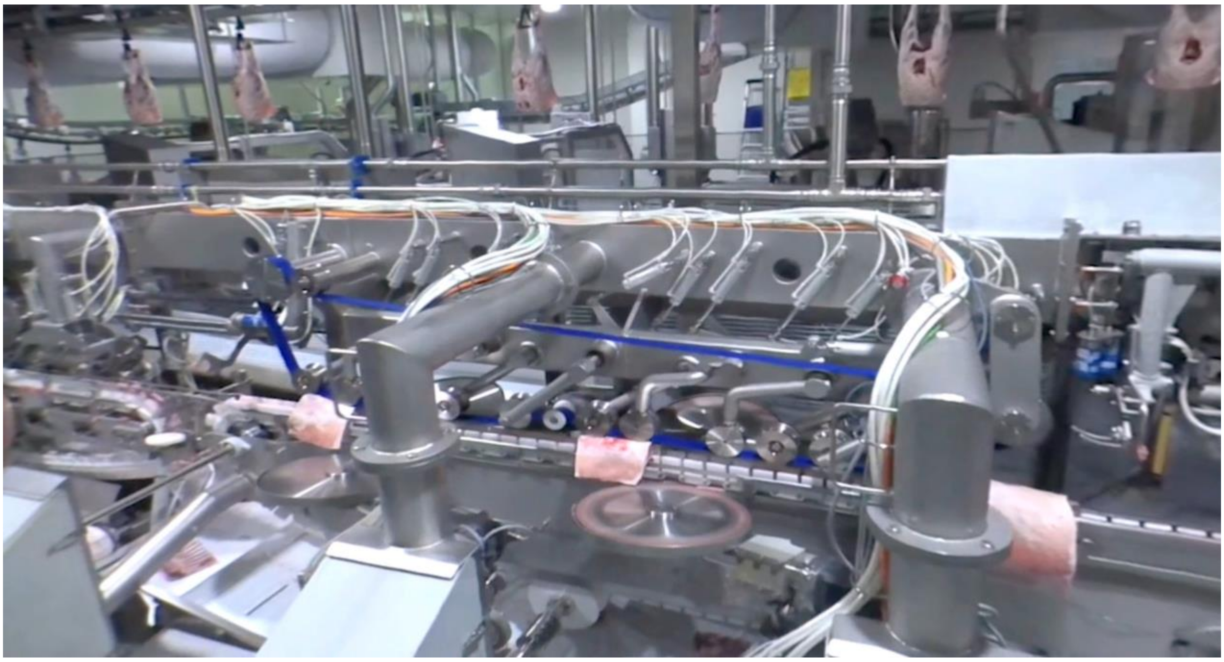


Figure 6: Middle machine flap cut station

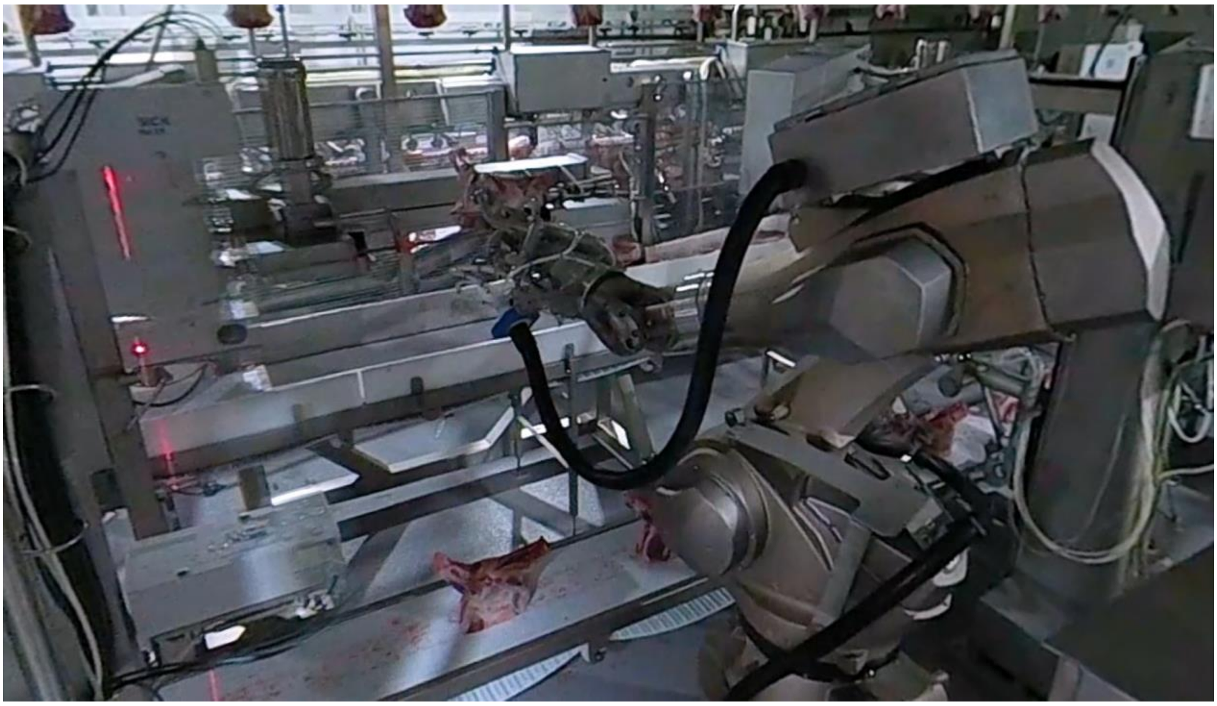


Figure 7: Forequarter processing robot and bandsaw

Figure 8: Forequarter processing system

The deliverables are shown in the following figures.

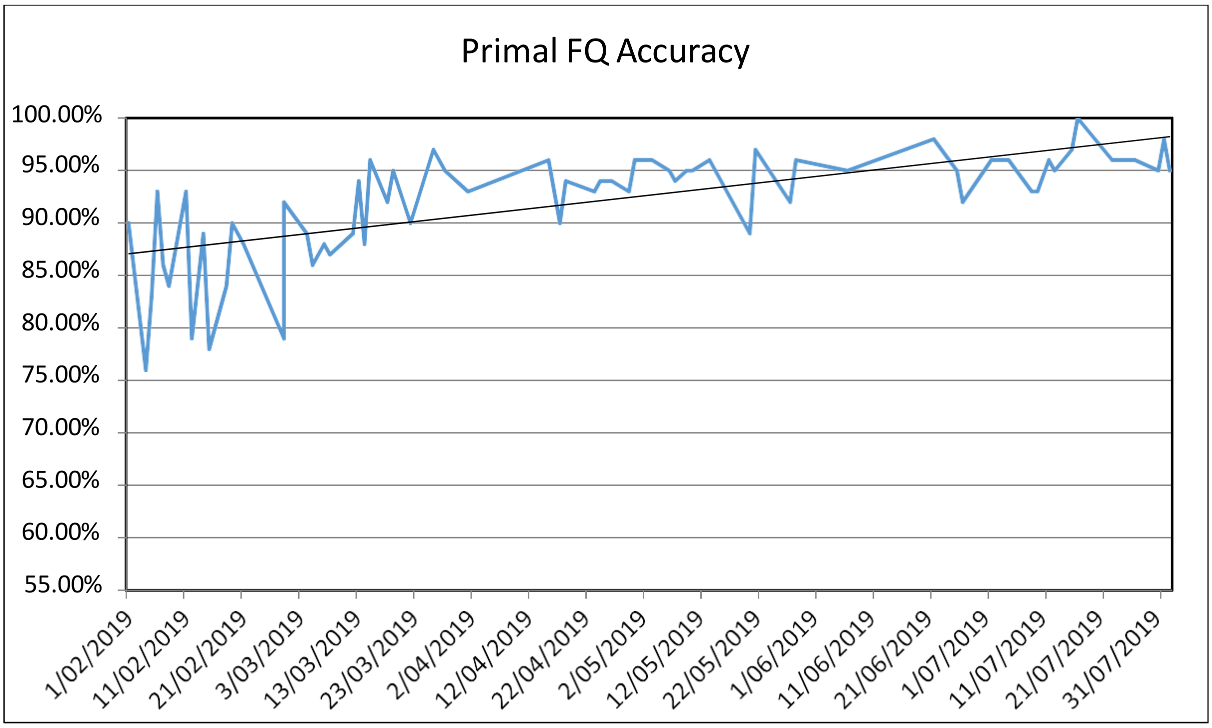


Figure 9:Primal Forequarter cut accuracy of imaged side (RHS of lamb) over time.

Figure 10:Chump off leg / Chump on saddle, cut validation.

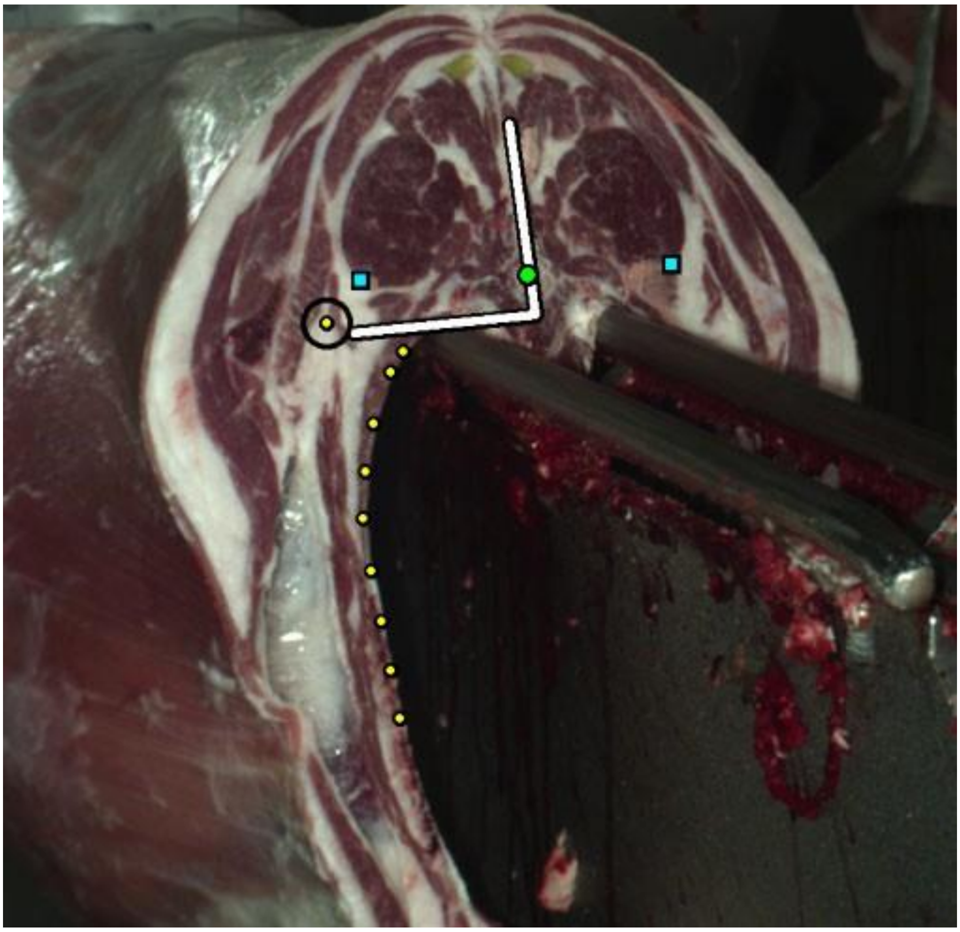


Figure 11: Rack analysis with enhance software

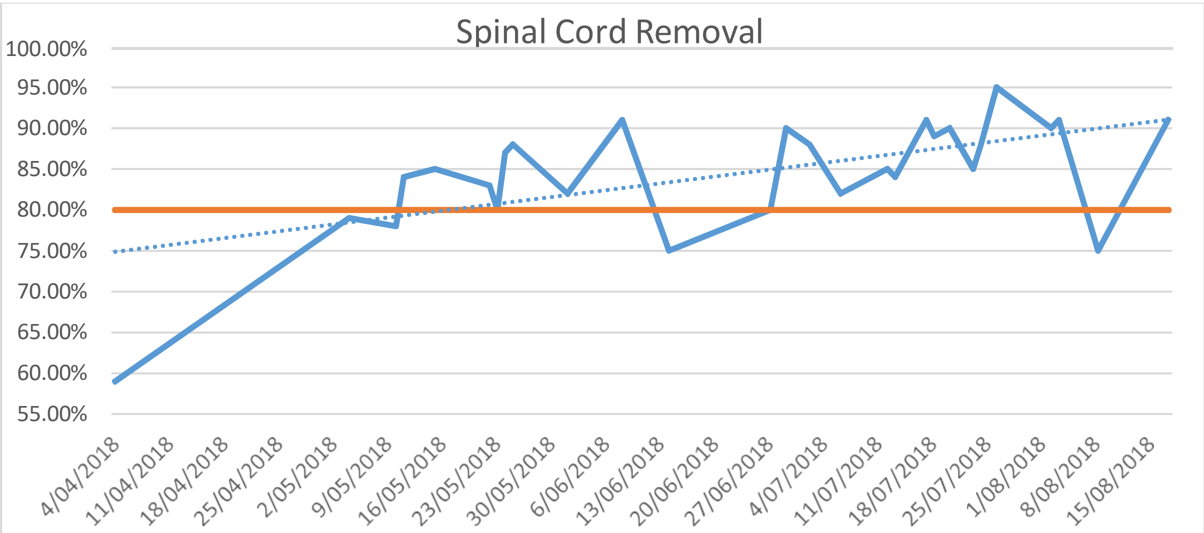


Figure 12:Spinal cord removal chart showing accuracy over time

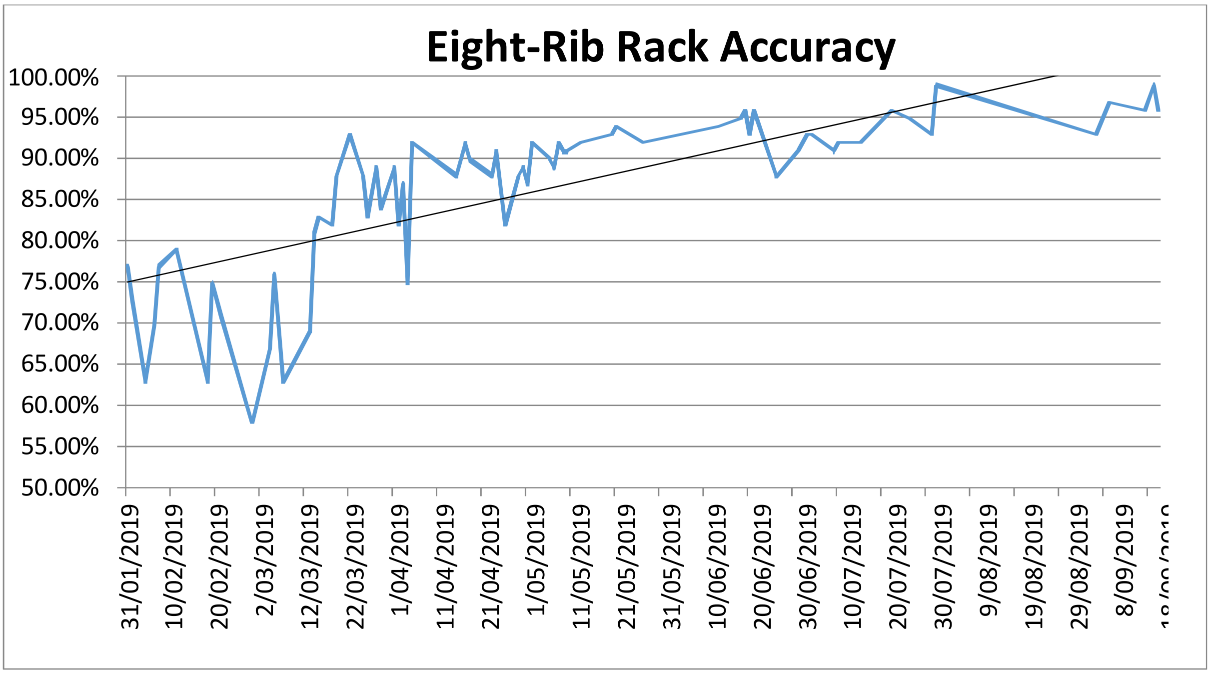


Figure 13:Eight-rib rack accuracy over time

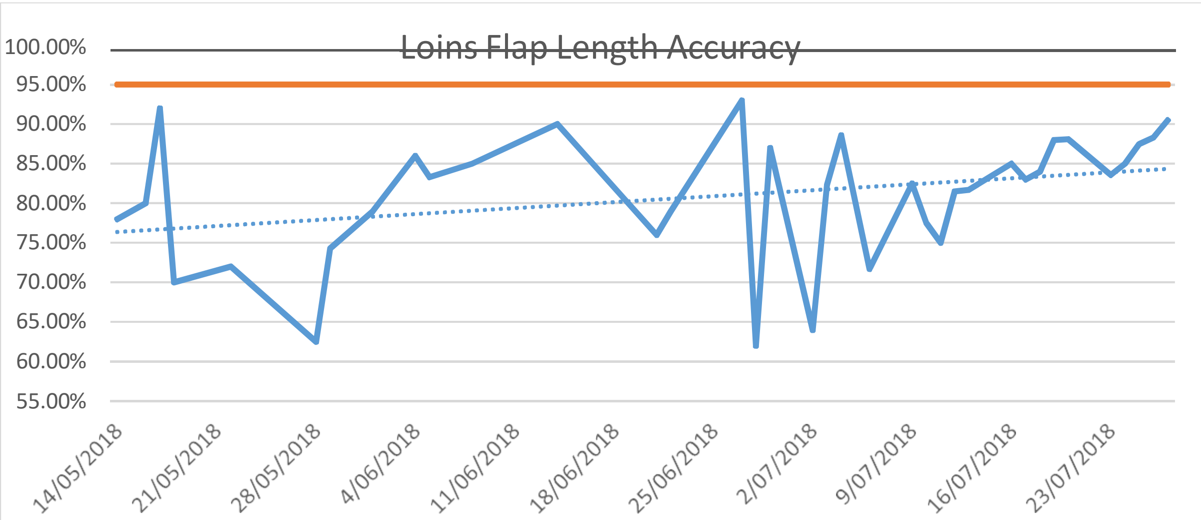


Figure 14:Loin Flap Length Accuracy over last 6 months

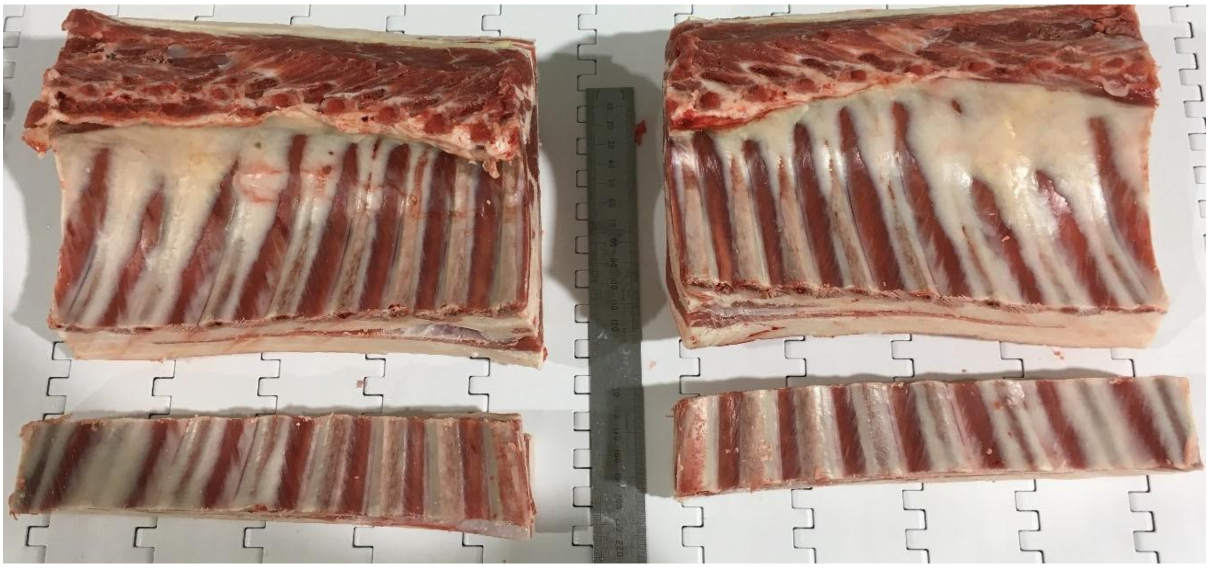


Figure 15: Short rib product deliverable, 70mm racks, 40mm short rib

Figure 16:Rack and chine from chine station.

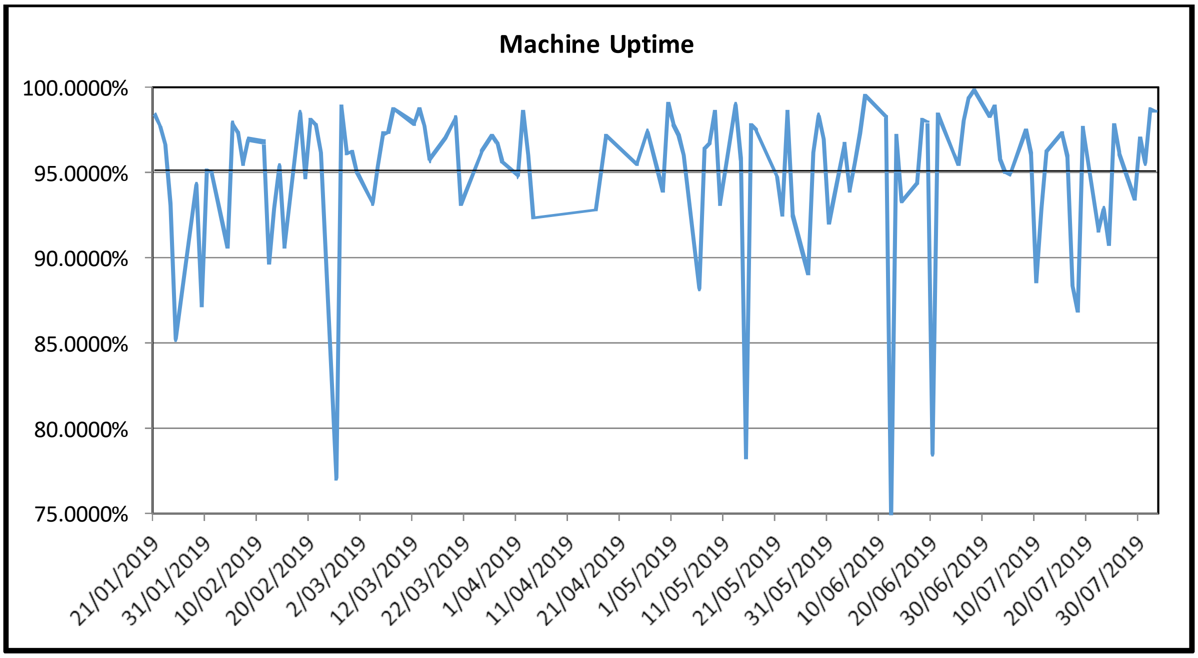


Figure 17:Machine Uptime for the past 6 months

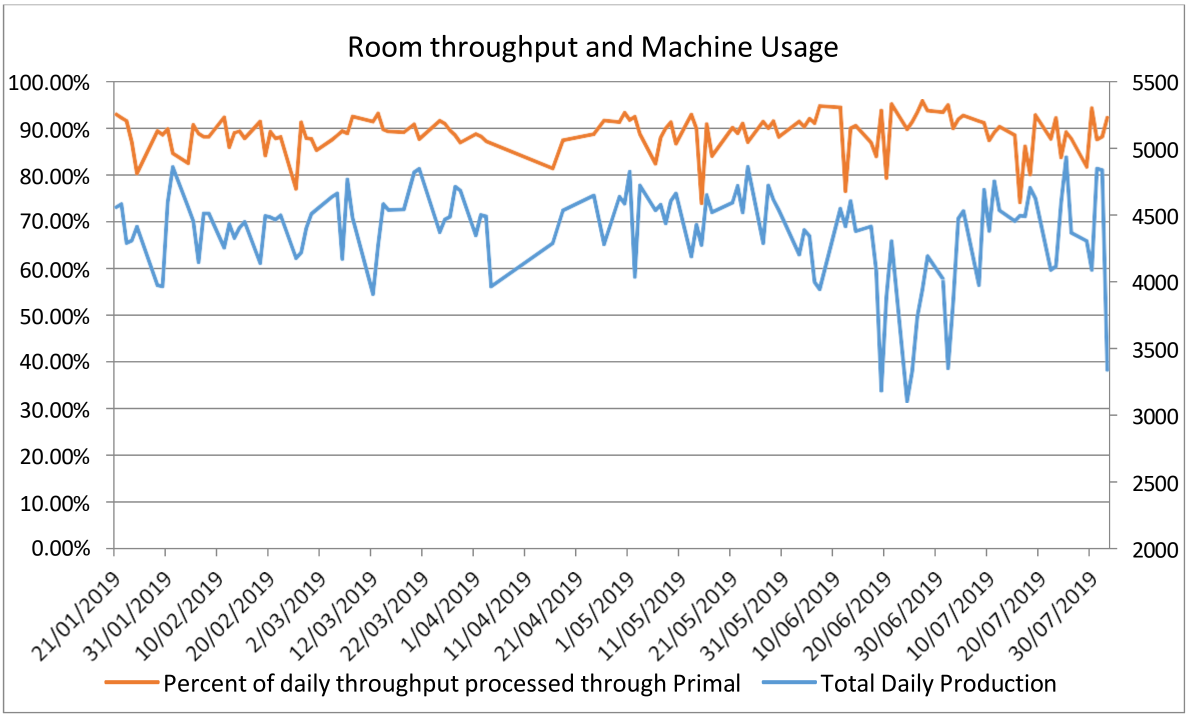


Figure 18:Machine throughput for the past 6 months

4.2 Loin Deboner processing machine development

4.2.1 Overall

Figure 19 shows overall views of the Loin Deboner, as was developed in milestones 11-16, and shipped back to the SCOTT factory for further development in milestone 31a.

Figure 19: Loin Deboner - Overall Views

4.2.2 Loading

The product is loaded to two parallel blades which located the spine centrally. The blades are tapered and form a scraping function as the product is transferred.

It was established that the spine condition effected the quality of the tenderloin removal.

This development is an enhancement on earlier location on the carriage which had issues when Aorta and salvage was present.

Additionally, it was found that the introduction of a scallop along the length, addressed a tendency for the scraper to dig into the bone and derail the product. An active continuous hold down was added to enable clamping the product down at the loading zone and enhance the hold down function.

Figure 20: Loading zone, scraper, hold down. Shows the scallop scraper

4.2.3 Tenderloin removal station

The tenderloin removal station consists of vertical blades adjacent to the spine, which also form the vertical datum for the process.

Then there are horizontal powered wheels which "pull" the tenderloin out from the skeleton.

The tenderloin is separated from the extremities of the transverse processes with horizontal blades.

This setup supersedes the previous setup with horizontal blades being the primary tenderloin removal means. The horizontal blades could not achieve the yield requirements given the variability of the transverse processes, including overall angles and various "nodules".

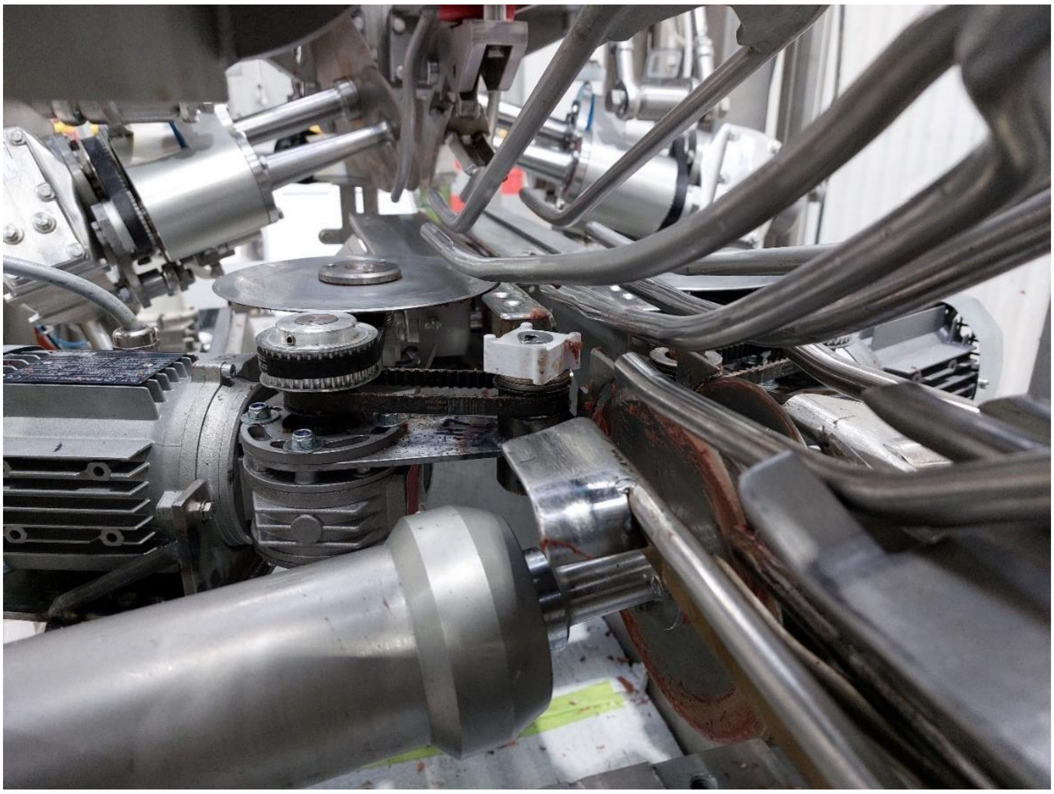


Figure 21: Tenderloin removal station. Showing vertical blades, TL removal wheel and associated mechanism and horizontal tail cutting blade.

4.2.4 Eye of loin removal station

The eye of loin removal station has the complexity of needing to remove product from around the button bones.

The solution developed in this research uses two vertical rotary blades and a fixed horizontal blade. The vertical rotary blades are both a small and a large blade. They are setup such as to create a cleavage which surrounds the button bone.

Rotary blades have been shown on previous projects, and confirmed in this research, to more cleanly cut the connective tissues between the meat product and the bone. The rotary blades also maintain the cutting action longer between sharpening.

The result in this research was to use the rotary blades adjacent to the spine where the connective tissue is prevalent and the fixed blade over the transverse processes.

The vertical rotary blades mounting is constructed such as to be compliant and self-adjusting to skeleton variation. Milestone 15 identified a requirement for the vertical blade height compliance to be independent of each other, which was incorporated in Milestone 31a.

The fixed blade is "tied" to the height of the large vertical rotary blade so that it follows the variable height of the transverse processes.

The transfer through the process utilises a clamp on the spine. The clamp has a raised ridge to affect the vertical datum and horizontal teeth to form the horizontal clamp. Additionally, a barb is incorporated into the trailing end of the clamp to ensure the product cannot slip backwards.

Milestone 15 identified jamming as a highly undesirable source of down time. This was addressed with the improvement in following the bone and the enhanced clamp which increases the driving force and maintains uptime, even if there is bone interference.

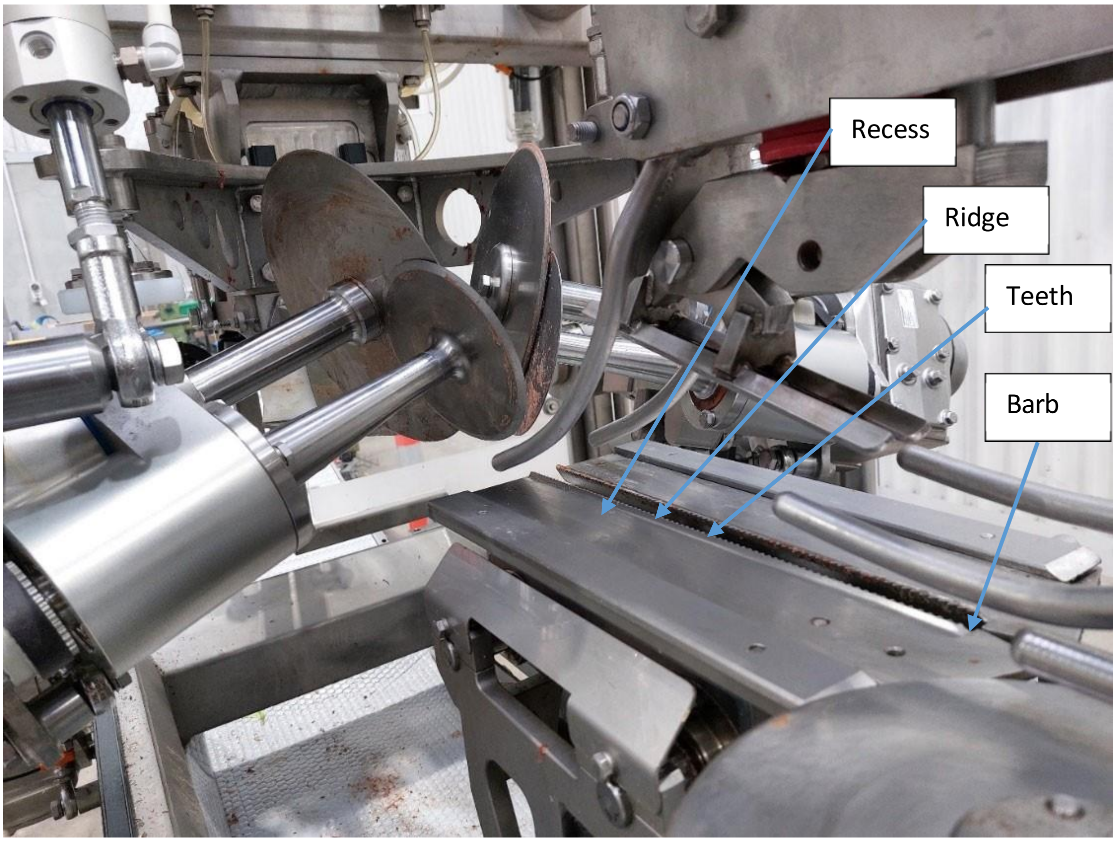


Figure 22:Small and large vertical rotary blades, clamp with vertical location ridge, clearance for transverse processes and the barb.

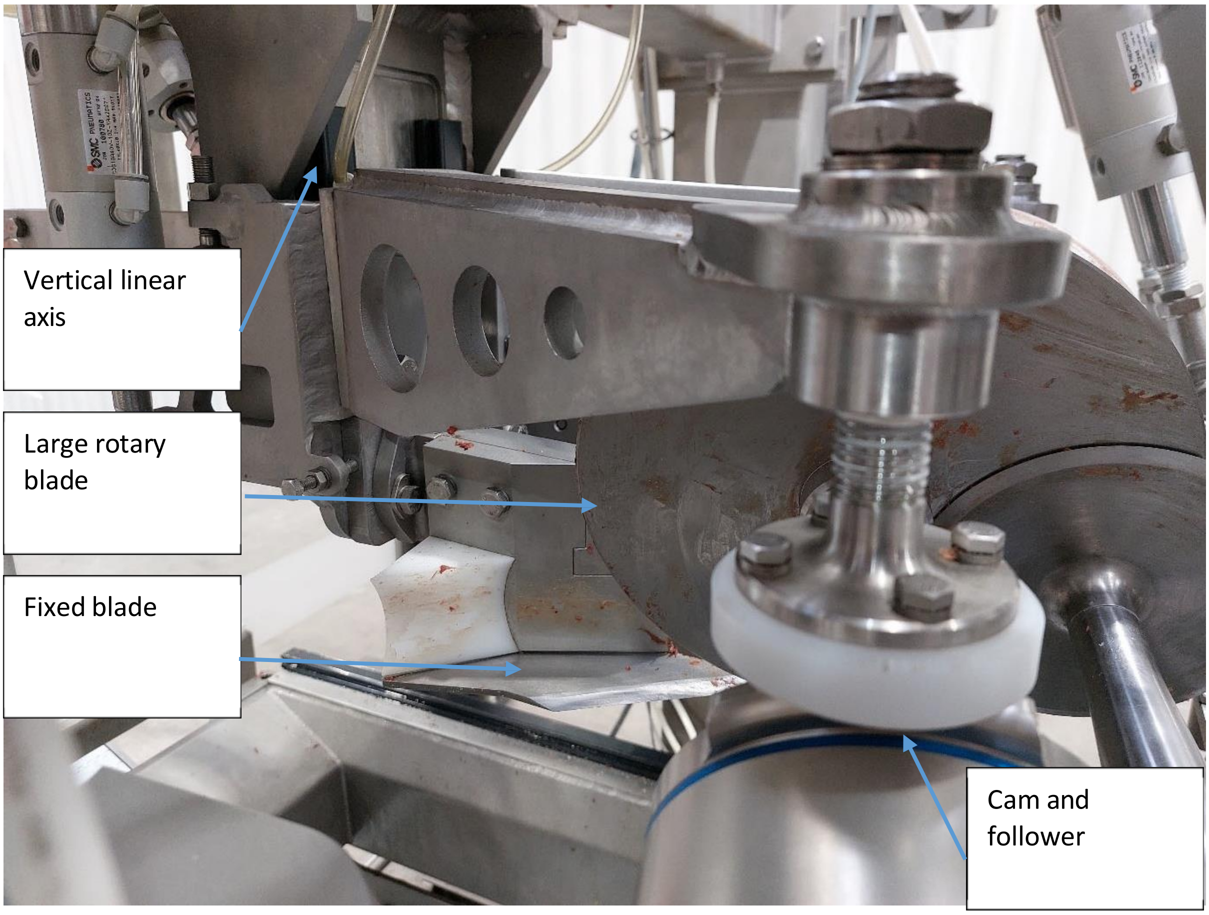


Figure 23: Remade fixed blade, vertical axis and bone following means

4.2.5 Process product Results

4.2.6 Qualitative yield assessment

4.2.6.1 Loading

On limited number of trials constrained by running the SCOTT factory, the process now enables loading the product accurately directly to the spine. The scraping is clearing the ventral region of the spine extremely well as shown in the process product results above. Bare vertebrae are visible. The feeding of the product is now successful, without tendencies for the product travelling off at an angle.

4.2.6.2 Tenderloin removal

The tenderloin removal is as per the photographs above. The SCOTT assessment is that the removal is like a good example of the manual process. The percentage where the process is not ideal and results in a non-optimum yield will need to be determined in a processor trial. Qualitatively, the tenderloin is being separated from the seam and the corner adjacent to the spine is being cleared out. For a significant portion of the tenderloin, for most of the time, the product is being extracted from within the intercostals.

The result is qualitatively assessed as being superior to the trials at the processor site in the last milestone.

4.2.6.3 Eye of loin removal

The station has not jammed in any of the trials since the milestone 31a upgrade.

The eye of loin removal, qualitatively, has improved the yield recovery compared to the trials at the processor site in the last milestone.

4.2.7 Trial 145 example

Figure 25:20211008 145 Eye of loin removal result

Figure 26:20211008 145 Tenderloin removal result

4.2.8 Machine performance

Acceptable performance was achieved for the following requirements.

1. "Dry" cycling reliability
2. "Wet" commissioned and machine is reliable.
3. Yield is judged as greater than the BLM machine for the eye of loin removal and the manual process for the tenderloin removal.
4. Safety
5. Theoretically the cycle time was within the requirements, but difficult to validate before a significant production run is performed, because of the manual load.
6. Only one operator is required.

Note: Flap length will need to be kept under 0-25mm for the currently developed machine.

4.2.9 Integration into SCOTT lamb middle processing machine

The future plan is to integrate the Loin Deboner, as developed here, into the SCOTT lamb middle machine. The Loin Deboner will need to be mature, having processed many products at a processor before it will be viable to integrate, because of the risk of downtime and yield loss for the processor.

The makeup of the loin tenderloin and eye of loin dictates that the loin has to be processed in the direction of from the leg end to the rack end. This is the opposite direction that the loin and racks are processed down the SCOTT middle machine.

In the middle machine the loins have the flaps removed and then are either ejected or bypass the chining station and go through the split station.

The integration concept proposed is that the loins, for deboning, would come out of the middle machine at the transfer between the flap removal station and the chine removal station.

The transfer would be replaced with a robotic device which clamps over the ends of the loin spine, or rack, and transfers the loin products to the Loin Deboner infeed or the racks to the chine station. An eject could also be incorporated. The Loin Deboner would be situated perpendicular to SCOTT lamb middle machine.

4.2.10 Business case review

It is expected that uptime will exceed 95% typical of this type of machinery and that yield exceeds current processes. However, a good estimate will require significantly larger trials at a processor site.

5. Conclusion

5.1 Primal and Middle machine

5.1.1 Key findings

Many of the issues that were experienced were both not foreseen and resulting from inputs or environment that the equipment has not faced in previous installations.

Carcase transfer and integration has provided several key learnings regarding the setup and installation approach for future installations. Measurement methodology used to benchmark machine cut accuracy has been significantly improved to provide higher returns and benefits. Carcase skid and gambrel movement proved to be a key hurdle in initial commissioning stages and carcase stability during the transfer process and across integration points.

It was found that input carcase quality had a profound effect on the performance of the system (as it would with manual cutting also) and having the DEXA, Primal and Middle system in place has assisted JBS to identify upstream carcase processing issues readily and address them on a timely basis which further adds benefit from the system to JBS business.

Onsite maintenance was shown to be critical for items such as camera cleaning and checking setups

The CNN approach has been shown to significantly improve vision systems capability

Complex systems, like these systems, do require comprehensive diagnostics to enable responding to failures in a timely manner with the generalist support staff on site.

5.1.2 Benefits to industry

The DEXA, Primal and Middle systems have been running at varied levels of capacity since approximately the 1st of November 2017 (Refer to Milestone report for Milestone 6). The modules are integrated and processing 100% of the processing specifications at production speeds up to 10 carcases per minute. Scott have finished optimising the system and have achieve the accuracy specified. JBS have full unbridled use of the machine for production. The overall reliability of the machine has exceeded machine specification and is in general been better than other similarly installed machines elsewhere. JBS operators, cleaners and maintenance have been trained in the use and upkeep of the system and the system is now run solely by JBS.

It has been found that the system operation should prove to return all of the benefits identified as key to the DEXA Primal and Middle ROI once optimisation is complete, and the setup has integrated seamlessly with the wider JBS plant and operations.

It appears at this stage that the wider project objectives to ensure that system benefits can be linked and further exploited through the JBS "Buy/Make/Sell" business model will be achievable.

5.2 Loin Deboner processing machine development

5.2.1 Key findings

The loin deboning process has presented significant challenges to achieve the processor requirements regarding refinement of the removal of product from the skeleton. The viability of the new machine is measured by the yield exceeding current means of boning, such as the BLM machine for eye of loin removal and manual tenderloin removal.

The development reaffirmed the difficulty of separating meat product from the skeleton with a yield higher than the current mature processes. The development also highlighted the impact of product variation, even between New Zealand and Australian processors.

The SCOTT team, who have significant specialist skill in meat processing machinery development utilised an iterative development process. Where concepts were scientifically created and validated with prototyping. Then a production machine was designed and built, incorporating the validated prototypes. Given the risk of changes and tuning, significant adjustment and system interface points was incorporated into the machine. This strategy has enabled iterating through refinements as portions of the process were validated. The result is a machine with a growth path to a commercial machine. This development process would be recommended for future challenging meat developments.

Trials on the processors site were performed in milestone 15 and 16 which identified shortcomings regarding required yield and uptime. A subsequent milestone, milestone 31a, was added to further develop the Loin Deboner and address the shortcomings. Various inventions and developments have been applied.

With the further developments the Loin Deboner process has been assessed as removing tenderloins and eye of loins as per the requirements established. Where indications from the trials in the SCOTT factory for yield and uptime have met or exceeded the current process means.

Quantitative validation of the yield and uptime has not been possible to date on a processor site or on processor quantities.

5.2.2 Benefits to industry

The Loin Deboner development will be able to be a standalone commercial loin processing machine which will enable refining the process and be a viable machine for the processors that a standalone machine suit.

The Loin Deboner development will be suitable for future integration into the SCOTT lamb middle processing machine.

Future integration into the SCOTT middle machine will require the process to mature to minimise the risk of loss of yield and downtime for the processor.

Retrofitting into existing SCOTT middle machine sites is likely to be impeded by space constraints.

The target audience is lamb processors, typically with a production rate at the top end of 10 carcasses per minute.

This research has delivered the following:

- Both tenderloin and eye of loin removal in a single machine
- Processing rate of 10 products per minute.
- Enhanced yield, tenderloin removal, relative to the manual process.
- Enhance yield, eye of loin removal, relative to current available machines.
- Labour savings from the increased rate and automated unloading.
- Process reliability should exceed 98% uptime.
- Health & safety improvements
- Reduced machine footprint dimensions, for the equivalent processing capability.

6. Future research and recommendations

6.1 Primal, Middle and Forequarter processing machines

It is anticipated that the issues and learnings from this research will further improve future installations by ensuring that correct mitigation can be put in place at the time of installation or during the machine build.

Further research opportunities include:

- Further development of carcass stability and X-Ray scanning accuracy
- Application of 3D vision systems for the likes of rib length determination
- Further CNN application to enhance accuracy both for X-Ray analysis and rib length determination
- Use of DEXA data for value-add opportunities

6.2 Loin Deboner

The recommended next step for the Loin Deboner development project is to perform volume trials at a processors site. Product yield, uptime and manual loading cycle rate would be measured in the trial.

To validate the machine on Australian lamb, the machine will need to be trialled at an Australian processor.

A further development phase and tuning is likely to be required, in response to the findings from the trials.

Machine reliability and issues, typically associated with the environment are also likely to become evident and need responses ones the machine is put into production.

On the conclusion of meeting the processor requirements, the business case could be updated.

7. References

Maunsell, S. (2020). *P.PIP.0466. Milestone 15. Lamb DEXA grading with producer feedback, Value Chain integrated system to deliver the JBS "Buy/Make/Sell" Strategy.* Sydney: MLA.

8. Appendix

8.1 Milestone 31a Loin Deboner processing machine further development

8.1.1 Milestone 31a objectives

The objectives for milestone 31a were:

- Further development regarding issues identified in milestone 15. (Maunsell, 2020)
    - Product jamming and associated downtime
    - Tenderloin yield
- Site implementation, tuning and product trials

Performance status

- In milestone 15 numerous trials were run at a JBS processing site. Shortcomings in performance were identified and quantified. The shortcomings prevented, the project progressing to installing the machine on the production line.
- Given the shortcomings and the Covid19 constraints the call was made to ship the machine back to the SCOTT factory in New Zealand for further development and factory trials.

8.1.2 Overall

Figure 19 shows overall views of the Loin Deboner, as was developed in milestones 11-16, and shipped back to the SCOTT factory for further development in milestone 31a.

Figure 27: Loin Deboner - Overall Views

8.1.3 Loading

8.1.3.1 Enhancement to the loading, location, and spine scraping

To remove the influence of the Aorta and salvage residual on the spine the loading concept was changed from loading onto the carriage to loading onto fixed bars.

The initial further development incorporated the spine scraper into the machine just in front of the vertical blades. Where the principle of the manual scraper replicated. The scraper was compliantly mounted.

It was established that the spine condition effected the quality of the tenderloin removal. Therefore, the spine scraper was reworked again and enhanced. The result was to replace the loading bars with a full-length spine scraper. It was determined that the full-length spine scraper provided excellent loading location. And the full-length spine scraper had a greatly reduced angle of attack which gave superior scraping performance.

Additionally, it was found that the introduction of a scallop along the length, addressed a tendency for the scraper to dig into the bone and derail the product. An active continuous hold down was added to enable clamping the product down at the loading zone and enhance the hold down function.

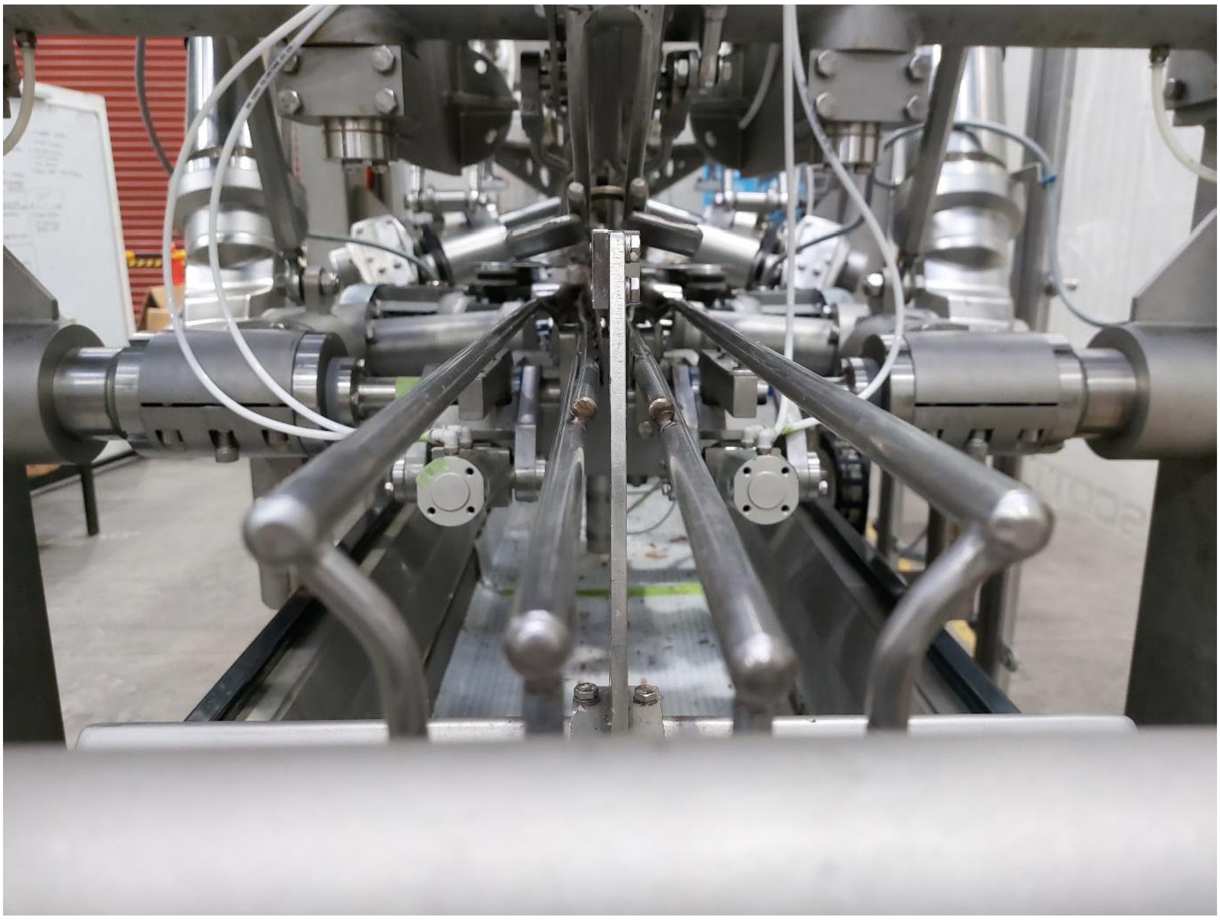


Figure 28: Loading arrange onto the fixed bars and the transfer pusher

Figure 29: Loading zone. Showing scrapers and full length hold down.

Figure 30: Loading zone, scraper, hold down. Shows the scallop scraper

8.1.4 Tenderloin removal station

8.1.4.1 Tenderloin removal

The tenderloin removal station originally consisted of both vertical blades and horizontal blades. The vertical blades have remained unchanged as they provide excellent performance in connection with cutting connective tissues down the side and into the corner of the spine. The vertical blades still create the vertical datum.

Extensive tuning was performed with the horizontal blades, including:

- Various blade setup angles – both directions
- Various product supports – both on entry and after the cutting edge
- Various blade bevels and sharpness.

However, the blade concept is constrained to being flat over a significant area and the circular geometry created product entry issues when dealing with products with transverse processes which weren't flat. Nodules and out of line transverse processes were cut off. The entry issues included cutting down the wrong side of the transverse processes for a small percentage of products. Therefore, this concept was dropped.

Many alternatives were developed and tried, either on the bench or incorporated into the machine.

The preferred approach encountered was the introduction of a powered wheel (referred to as the TL removal wheel). The TL removal wheel removes the tenderloin with a pulling action. The action has similarities to the manual process. Various wheel shapes, speeds and positions were developed and trialled.

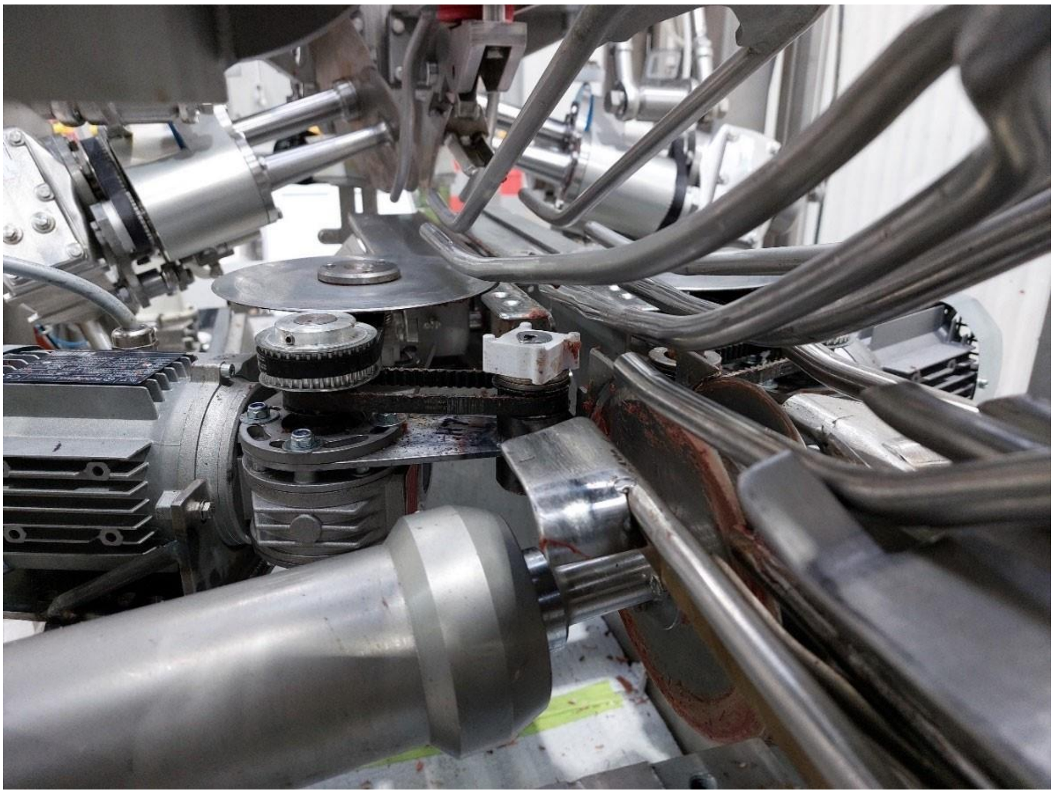


Figure 31: Prototype TL removal wheel and tail cutting blade

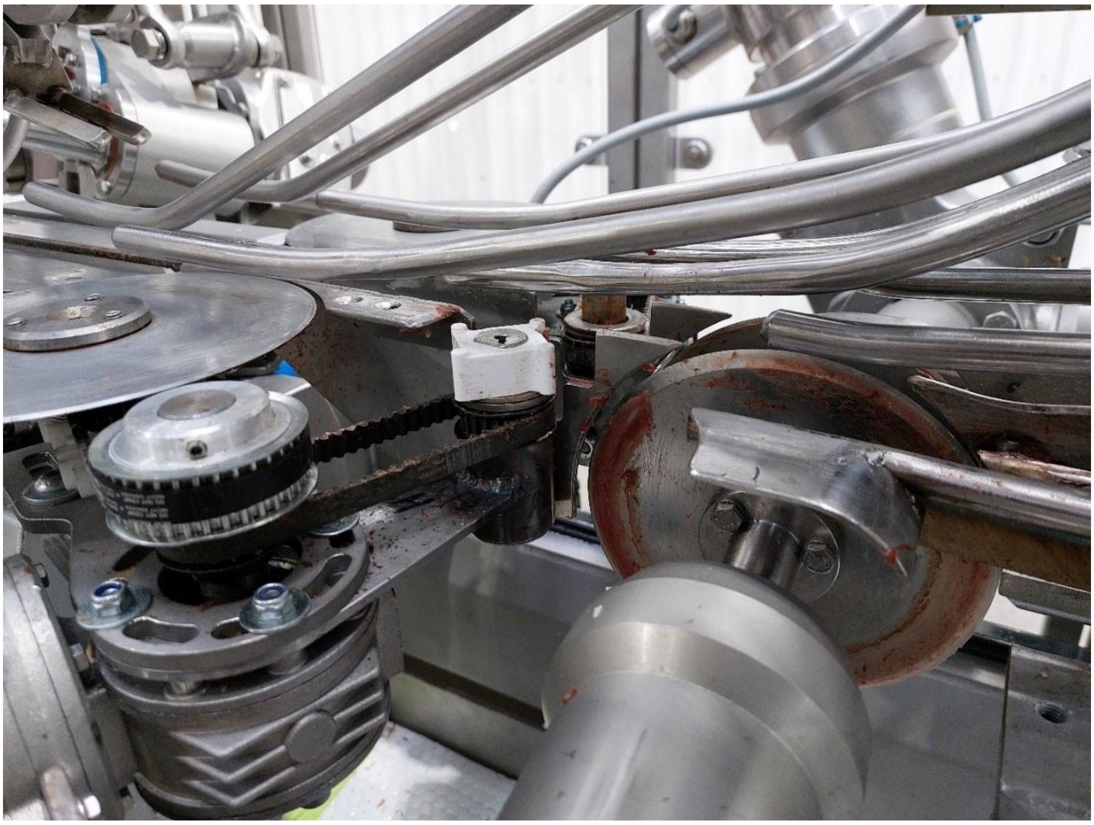


Figure 32: Tenderloin removal station. Showing vertical blades, TL removal wheel and associated mechanism and horizontal tail cutting blade.

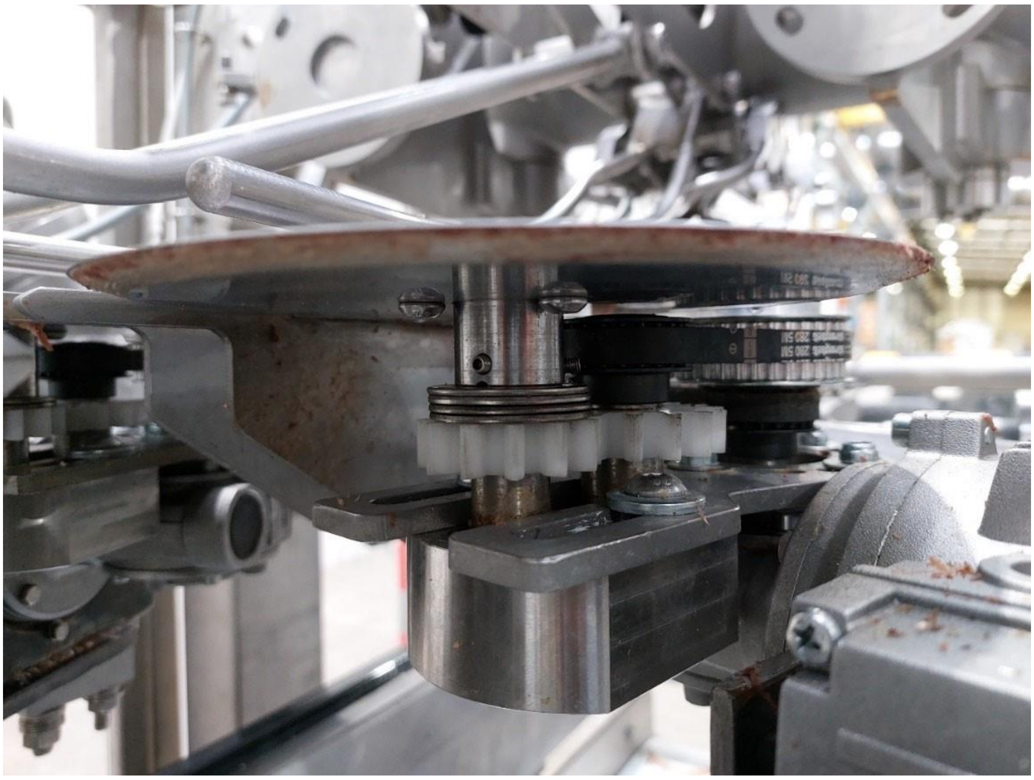


Figure 33: Prototype TL powered wheel and counter rotating tail cutting mechanism

8.1.5 Tenderloin tail cutting process

The tenderloin is removed by the TL removal wheels but was found to be strongly adhered by connective tissue to the ends of the transverse processes.

Various alternative TL powered wheel geometries were trailed and various fixed blades. The preferred solution was the reintroduction of a horizontal blade. It was found that best performance was obtained with the blade rotating in the opposite direction to the TL removal powered wheel. The prototype is shown in **Error! Reference source not found.**.

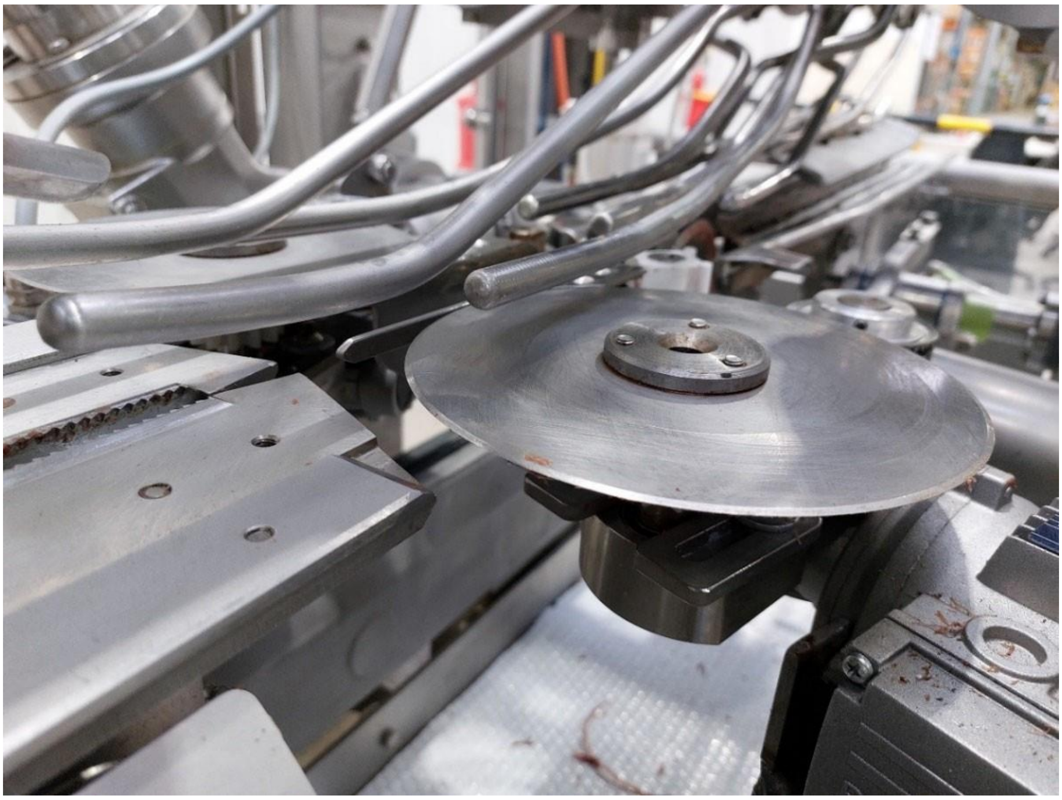


Figure 34: Tenderloin tail cutting blades

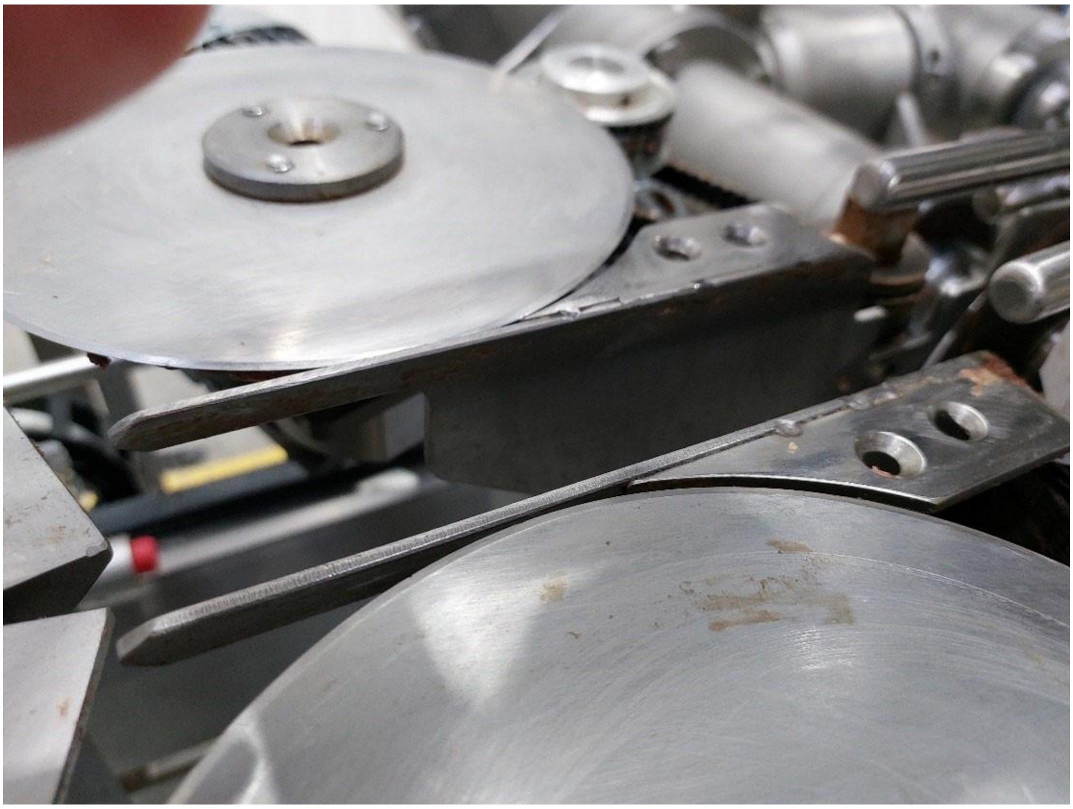


Figure 35: Tenderloin tail cutting blades and associated vertical height setting guides

8.1.6 Eye of loin removal station

8.1.6.1 Carriage clamp enhancement

The key performance short fall in the trials at the processor was product jamming and causing down time. The root cause was due to blades not adequately adjusting to the skeleton and hitting bone. However, changes were made to increase the security of holding the product. The changes were;

- The introduction of a barb engaged at the trailing end of the product to ensure the product cannot slip back in the clamp.
- A defined ridge for the datum onto the underside of the transverse processes adjacent to the spine, and clearance for the remainder of the transverse process. With these details correct vertical location is ensured.
- Enhanced saw teeth detail on the clamp itself to provide an aggressive clamping means.

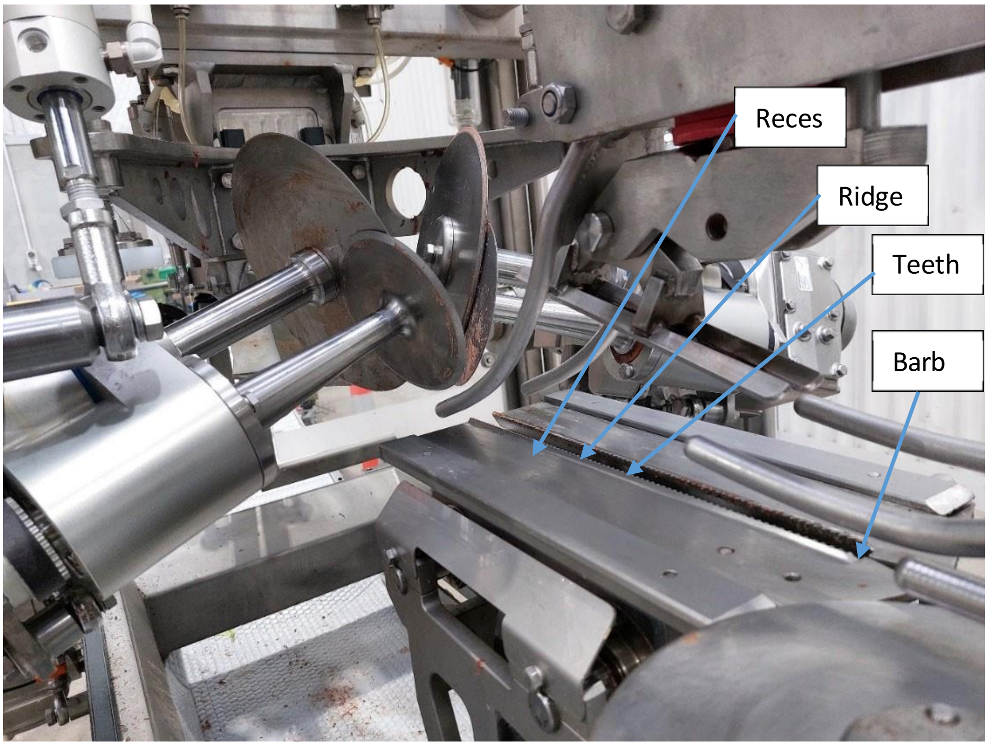


Figure 36:Remade clamp with vertical location ridge, clearance for transverse processes and the barb.

Figure 37: Carriage clamp details

8.1.6.2 Fixed blades automatic height adjustment

In response to the jamming failure mode the self-adjustment of the height of the fixed blades was enhanced. The functionality was achieved by using the datum established with the large rotary blade to drive the height of the fixed blade. The fixed blade was mounted to a vertical linear slide and a cam means added which is driven off the large blade assembly.

Additionally the geometry was refined to overlap the fixed blade with the region cleared by the large rotary blades. This enabled the “balling off” of the tip of the fixed blade to assist with the blade avoiding cutting into any raised portions of bone.

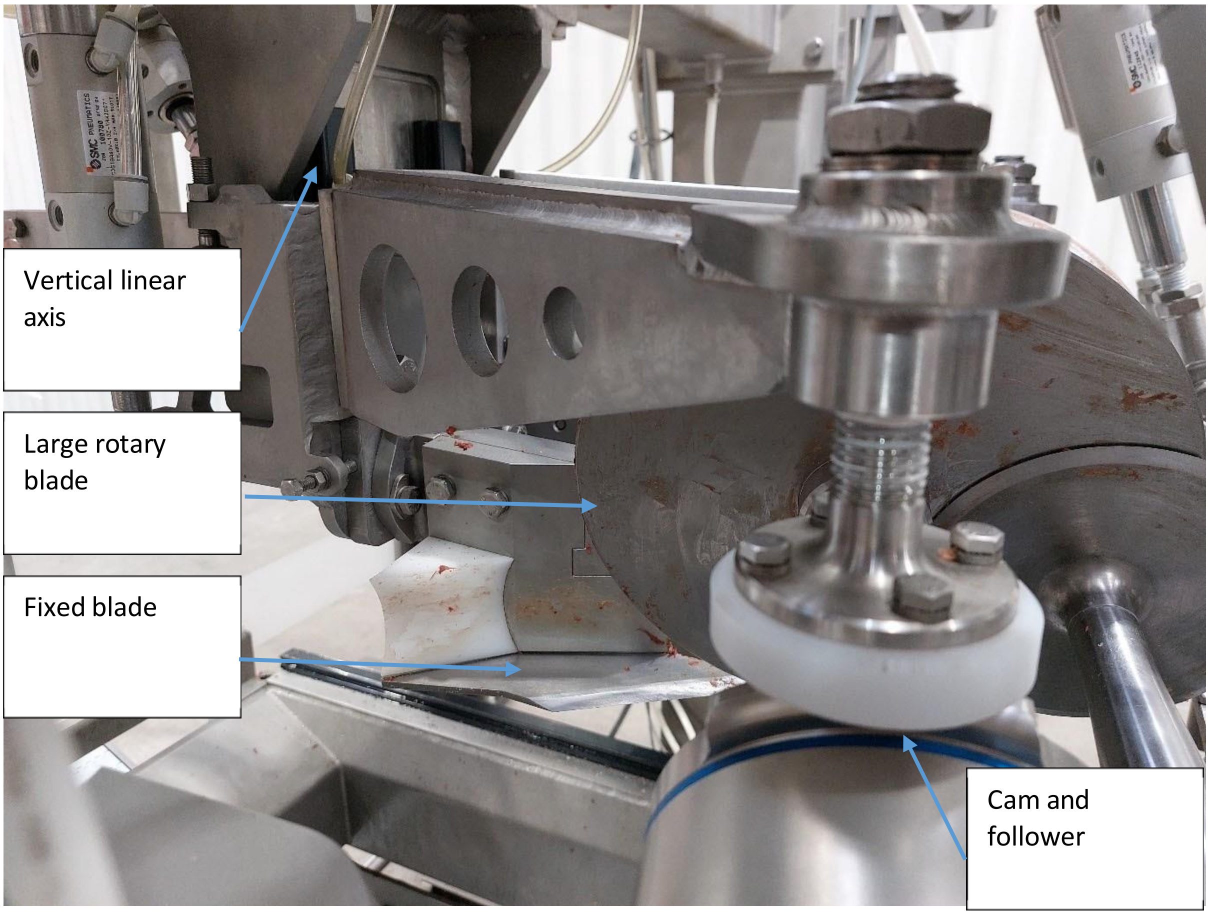


Figure 38: Remade fixed blade, vertical axis and bone following means

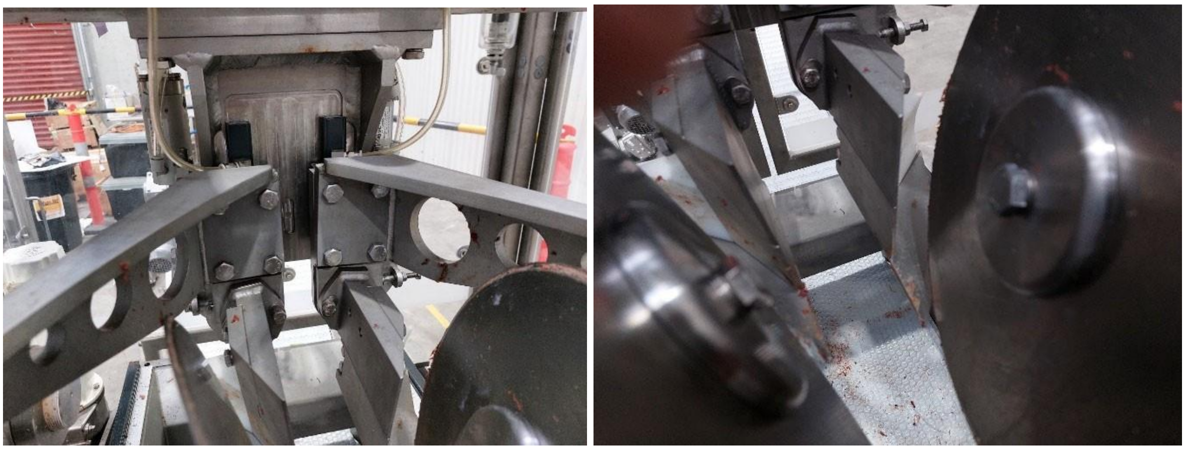


Figure 39: Fixed blades vertical axis & detail

8.1.6.3 Feather bone/button bone yield

In response to the jamming failure mode but avoiding loss of yield, the small rotary blade height was made independent to the large rotary blade. This came out of learning that the ideal height for the small rotary blade to the large rotary blade was variable and acceptable prevention of jamming or yield loss was unachievable. The small rotary blade was pivoted around the large rotary blade axis to effect independence.

Figure 40: Eye of loin removal station - overall assembly

Figure 41: Eye of loin removal station showing blades detail including geometry between the blades that clears the button bones.

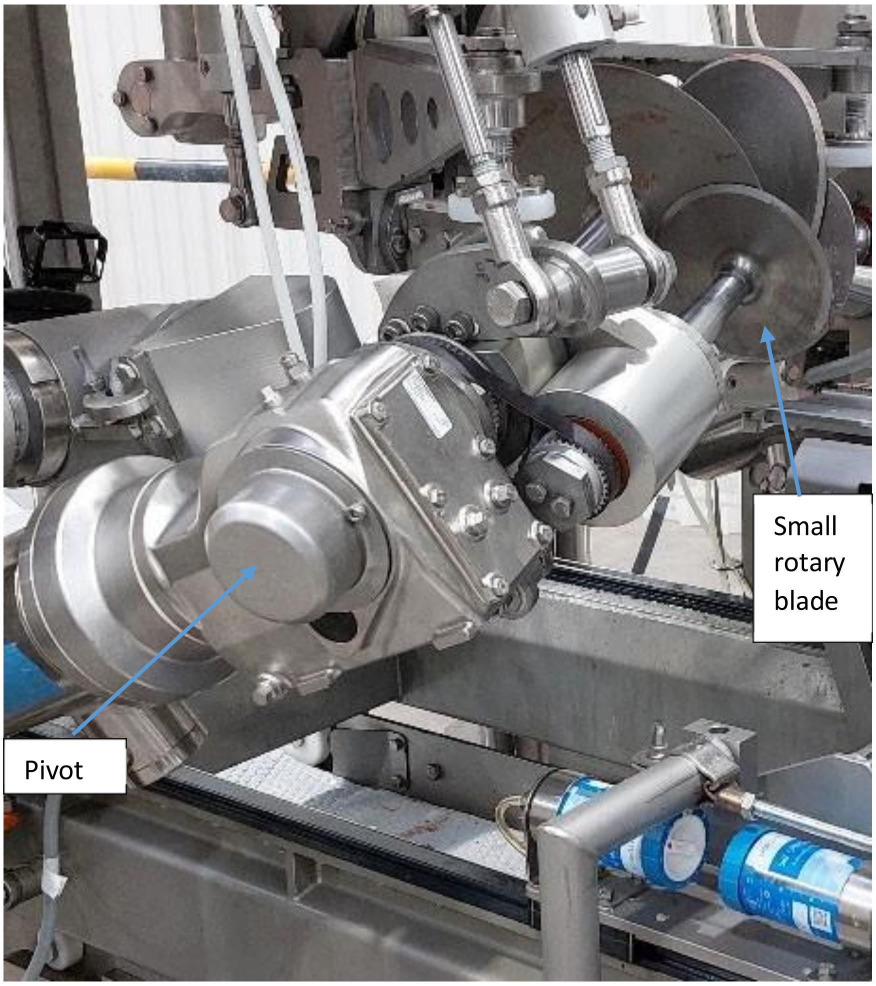
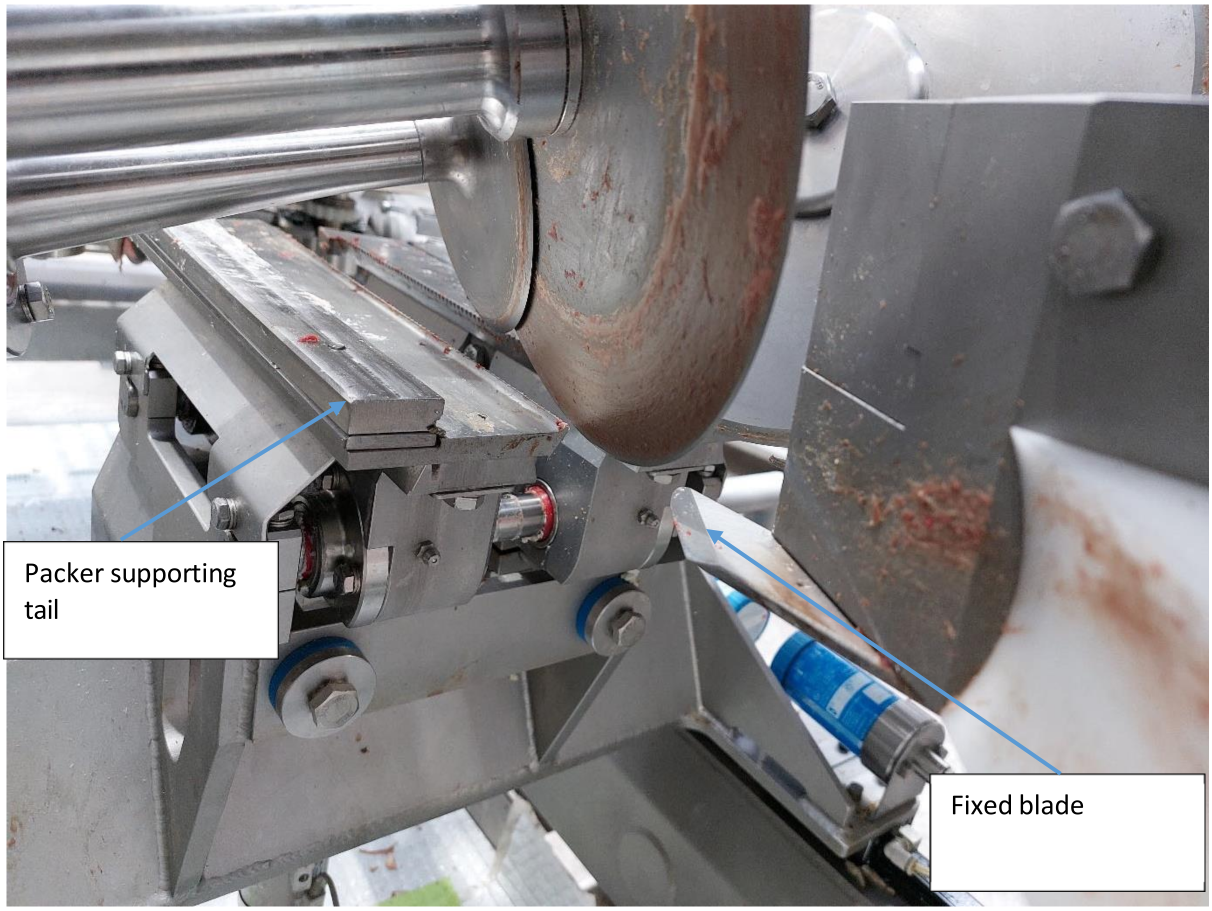


Figure 43: Small rotary blade pivoted about the large blade axis

8.1.6.4 Eye of loin removal from the extremity of the transverse processes

As part of avoiding the fixed blades jamming on the transverse processes, but also maintaining yield and avoiding cutting into the transverse processes excessively, an improved solution was required. The solution developed was to introduce a packer which lifts the "tail" of the product up above the top of the transverse processes. The fixed blades were cut down to fit adjacent to the packer and to ensure separation of the product from the bones.



8.1.7 Process product Results

8.1.7.1 Trial 145

Figure 45:20211008 145 Eye of loin removal result

Figure 46:20211008 145 Tenderloin removal result

8.1.7.2 Trial 147

Figure 47:20211008 147 Eye of loin removal trial result

Figure 48: 20211008 147 Tenderloin removal trial result

8.1.7.3 Trial 150

Figure 49:20211011 150 eye of loin removal - highlight hitting end of ribs hard

Figure 50:20211011 150 tenderloin removal

8.1.7.4 Trial 154

Figure 51:20211018 154 eye of loin removal - thread of meat from rib extremity

Figure 52:20211018 154 tenderloin removal

8.1.8 Summary of machine performance

8.1.8.1 Qualitative yield assessment

8.1.8.1.1 Loading

On limited number of trials constrained by running the SCOTT factory the process now enables loading the product accurately directly to the spine. The scraping is clearing the ventral region of the spine extremely well as shown in the process product results above. Bare vertebrae are showing. The feeding of the product is now successful, without tendencies for the product travelling off at an angle.

8.1.8.1.2 Tenderloin removal

The tenderloin removal is as per the photographs above. The SCOTT assessment is that the removal is similar to a good example of the manual process. The percentage where the process is not ideal and results in a non-optimum yield will need to be determined in a processor trial. Qualitatively, it can be seen that the tenderloin is being separated from the seam and the corner adjacent to the spine is being cleared out. For a significant portion of the tenderloin, for most of the time, the product is being extracted from the intercostals.

The result is qualitatively assessed as being superior to the trials at the processor site in the last milestone.

8.1.8.1.3 Eye of loin removal

The station has not jammed in any of the trials since this upgrade.

The eye of loin removal, qualitatively, has improved the yield recovery compared to the trials at the processor site in the last milestone.

8.1.8.2 Machine performance

Acceptable performance was achieved for the following requirements.

7. "Dry" cycling reliability
8. "Wet" commissioned and machine is reliable.
9. Yield is judged as greater than the BLM machine for the eye of loin removal and the manual process for the tenderloin removal.
10. Safety
11. Theoretically the cycle time was within the requirements, but difficult to validate before a significant production run is performed, because of the manual load.
12. Only one operator is required.

Note: Flap length will need to be kept under 0-25mm for the currently developed machine.