Final report

LEAP IV Middle System Performance Upgrades and Value Engineering

Project code: P.PSH.1303

Prepared by: A. Soundy, M. West, S. Maunsell
Scott Automation and Robotics

Date published: 30 June 2023

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

This is an MLA Donor Company funded project.

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

Abstract

Scott Automation and Robotics (within its joint venture company Robotic Technologies Ltd) and Meat and Livestock Australia have been developing their vision of a fully automated bone-in lamb boning system that removes operators from bandsaw interaction, provides uniform boning room production speed and significantly increases yield. The vision is depicted in Figure 1.

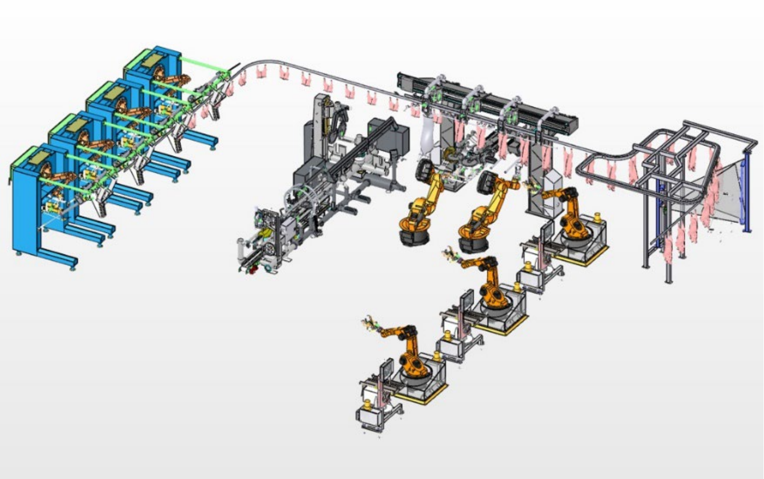


Figure 1 : Boning Room Vision (fully automated room)

There has been significant expansion and adoption since inception with the recent JBS Brooklyn system (2020) demonstrating a vertically integrated value chain operation with feedback to producers. This is evidence that significant opportunity exists to build and improve on the LEAP technology.

The fully integrated x-ray, Primal and Middle system technology has been successfully operating in Australia since 2012 and is now relied on as an integral, mission critical, component of efficient processing. Continued development by Scott and MLA has seen further benefit achieved off the back of the LEAP success.

It has been identified through ongoing analysis and support of the systems operating across Australia and New Zealand that there is substantial further benefit to be attained by upgrading the Middle system to achieve the next level in accuracy and reliability. This project looks to materialise this opportunity.

Executive summary

Current accurate processing from a LEAP IV Middle system provides a significant average net benefit per head of lamb processed. This benefit is primarily due to the increased accuracy of processing due to the LEAP IV Middle system when compared to the manual process. Since the inception of the LEAP IV Middle system, Scott Automation and Robotics (Scott) and MLA have continued development to gain further value for existing LEAP IV Middle installations, as well as new installations. This project targets several areas where processing accuracy could be improved further to provide additional benefits to the processor and the red meat industry.

The project targeted an upgrade for the LEAP IV rack and loin flap removal vision analysis and sensing. This upgrade used machine learning to improve the analysis for rack and loin flap removal. Additionally, new 3D sensing technology was trialled to investigate its use on the LEAP IV Middle system.

The major objectives of the project are:

1. Design and build retrofittable packages for the critical upgrades identified above for existing and future LEAP systems.
2. Demonstrate the upgrades to industry through installation on an existing LEAP system.

The retrofittable upgrade package was successfully designed and build and then demonstrated at an existing LEAP IV system. Unfortunately, due to communications issues the software was unable to run reliably enough to provide an on-site verification of the improvements.

The LEAP IV rack and loin vision analysis was rewritten and tested offline with manually labelled test data. The upgraded rack analysis was found to decrease the median error from 3.9mm (across all cut lengths) to a new median error of 1.1mm. Similarly, the upgraded loin analysis was found to decrease the median error from 5.7mm to 2.1mm (across all cut lengths).

A RGBD camera was implemented in a retrofittable mount to allow accurate 3D positioning of the loin. This was trialled on site and worked successfully. However, to remove the requirement for hardware changes and reduce the cost and complexity of the upgrade kit a machine learning system was trained to predict the 3D position of the loin. The current system uses information from the x-ray system, however, due to the product movement this existing system has a median error of 30.1mm for the product position on the rail. Due to the camera positioning this does not imply a 30.1mm error in cut position but a reduction in this error would improve the cut accuracy. Ultimately, the upgraded analysis was able to achieve a median positioning error of 3.7mm, which was comparable to the 2mm error from the RGBD camera. Due to the opportunity to create a software-only upgrade without the RGBD camera, as well as a more cost-effective upgrade this was the 3D option that was chosen for the upgrade.

Greenleaf Enterprises Pty Ltd (Greenleaf) performed a cost-benefit analysis with the aim of comparing the existing LEAP IV Middle system (Mk I) and the LEAP IV Middle system with the upgrade (Mk II). Due to the software communications errors Greenleaf were not able to collect a reliable sample size from the upgraded system so their comparison reflects the null hypothesis that both systems (Mk I and Mk II) are the same.

Offline testing suggests that the upgrade, once reliably implemented, should be able to improve median error on the rack and loin flap cuts by a factor of 2.7 – 3.5 which would represent a significant yield benefit to the customer.

The upgrade kit is being further improved in an upcoming LEAP IV Middle system with factory commissioning expected to begin in August 2023. Thorough factory testing and commissioning should allow for the communications issues in the upgrade software to be solved and the upgrade to become available to existing LEAP IV Middle systems, as well as new systems going forward.

Table of contents

Executive summary **3**

1. Background **7**

2. Objectives **7**

3. Methodology **8**

3.1 LEAP IV Rack and Loin flap removal vision and sensing upgrade **8**

3.2 Demonstrate the upgrades to industry through installation on an existing LEAP system **8**

3.3 Cost-benefit analysis methodology **9**

3.3.1 Data Quality Control 9

3.3.2 Cutting Yields 9

3.3.3 Operating and OH & S costs 9

3.3.4 Fixed Model Drivers 10

4. Results **10**

4.1 Demonstrate the improvements in vision analysis accuracy from the Rack software system upgrade. **10**

4.1.1 Rack analysis improvements 10

4.1.2 Loin analysis improvements 13

4.1.3 Develop and test the upgraded 3D Loin product image capture and analysis, in parallel with existing LEAP system on site 17

4.2 Deployment of Middle Vision Upgrade kit on site **21**

4.2.1 Bench testing of communications software (Melbourne site) 22

4.2.2 Dry cycle testing of communications software (Melbourne site) 22

4.2.3 Bench testing of communications software (New South Wales site) 22

4.2.4 Dry cycle testing of communications software (New South Wales site) 22

4.2.5 Production cycle testing of communications and analysis software (New South Wales site) 23

4.3 Updated Cost-benefit analysis **24**

4.3.1 Benefits 24
4.3.1.1 Spinal Cord Removal 24
4.3.1.2 Shortloin Pair - Flap Removal 24
4.3.1.3 Rack Flap Removal 25
4.3.1.4 Rack lost to Shortloin Pair 26
4.3.1.5 Chine Removal 30
4.3.2 Reduced Bandsaw Dust 30
4.3.3 Labour Savings (Reduced Staff) 30
4.3.3.1 Reduction in staff numbers (Bandsaw operators) 30
4.3.4 Labour Savings (Increased Productivity) 30
4.3.5 OH & S Issues 31
4.3.5.1 Capital Costs 31
4.3.5.2 Maintenance and Service Costs 31
4.3.5.3 Risk of Down Time 31
4.3.6 Summary Cost-Benefit Analysis 31
5. Conclusion 32
5.1 Key findings 32
5.1.1 Offline accuracy improvements 32
5.1.2 Offline 3D positioning improvements 32
5.1.3 Cost-Benefit Analysis 33
5.2 Benefits to industry 33
6. Future research and recommendations 34

1. Background

Scott Automation and Robotics (Scott) and MLA through strategic partnership have successfully developed and are rolling out to industry the LEAP III, LEAP IV and LEAP V automated primal, middle and forequarter bone in processing system for lamb. Scott and MLA were supporters of the initial adoption of the technology with the first systems going into production in 2012. These systems are still performing strongly and a further 13 systems are now in operation.

Since inception, Scott and MLA have continued development to gain further value and realise new opportunities presented by advances in technologies and through the continued operation of these systems in the field. Notable successful developments that are a direct continuation of LEAP include Xray sensing for accurate skeletal measurement, standalone lower throughput modules for small to medium size processors, carcase yield measurement using Dual energy Xray, system upgrades to improve yield and reliability, loin deboning and short rib processing.

Given the strategic importance and success of the LEAP systems to Scott, MLA and the Australian lamb industry this project looks to further develop the system to gain additional value for the lamb value chain through yield and reliability improvements.

The benefits of the LEAP system are well understood and documented. Improved accuracy of cut placement where there is differential product value across the cut delivers significant benefit to processors and producers plus OCM benefits.

This project builds on crucial learnings and developments that have been acquired through observing systems operating across a wide range of plants and products and target high value areas of benefit such as primal breaking and sub primal preparation cuts. The upgrades target improvements in design that increase the benefit from accuracy, achieve a reliable 10/min throughput as well as improve mechanical reliability. The upgrades will include the LEAP IV Rack and loin flap removal vision and sensing upgrade using 3D vision and machine learning to improve accuracy.

2. Objectives

The project targeted an upgrade for the LEAP IV rack and loin flap removal vision analysis and sensing. This upgrade used machine learning to improve the analysis for rack and loin flap removal. Additionally, new 3D sensing technology was trialled to investigate its use on the LEAP IV Middle system.

The major objectives of the project were:

1. Design and build retrofittable packages for the critical upgrades identified above for existing and future LEAP systems.
2. Demonstrate the upgrades to industry through installation on an existing LEAP system.

The production of a final report, detailing the upgrade packages was prepared.

3. Methodology

3.1 LEAP IV Rack and Loin flap removal vision and sensing upgrade

Flap cutting for the rack and loin is a key aspect of the LEAP IV system benefits to the customer. Currently the LEAP IV utilises a basic RGB analysis of the loin cut surface to identify the eye of loin and calculate the tangent edge from which the cut specification is measured from. This guides the blades in the flap cut station to remove the loin tails at a user nominated specification for every loin product processed. The most common specification in Australian industry is a 0mm tail which positions the cut directly adjacent and tangent to the eye of loin. The current cut specification accuracy is +10mm/-0mm of “Cut Spec” as shown in the image below. If the cut is made below 0mm it risks cutting into Eye muscle and losing valuable eye muscle to trim. Additionally, if the flap length is left too long there is an operator required to trim it back to specification.

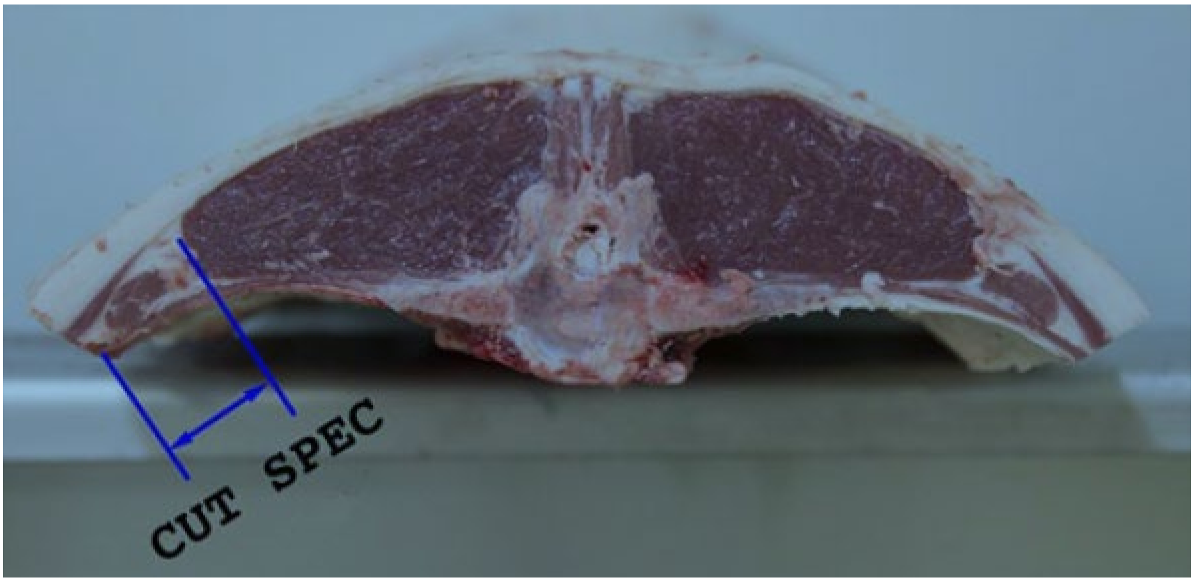


Figure 2 : Nominal saddle cut specification.

The existing RGB camera has limitations in determining an accurate cut position based on the 2D distortion incurred with optical positioning and parallax error. Recent analysis of operational systems has identified an opportunity to draw on advances in 3D vision analysis combined with artificial intelligence techniques to significantly improve the cut spec tolerance for flap cut path identification. This upgrade will implement a 3D image capture device as well as an advanced machine learning algorithm to position the cut specification line with a high level of precision.

As a result of this project Scott and MLA will have a number of upgrades that can be rolled out as retrofittable packages to any existing machines as well as incorporated as standard into new machines. This will present an opportunity for greater ROI for these machines and for the industry as a whole.

3.2 Demonstrate the upgrades to industry through installation on an existing LEAP system.

Once the system has been trained sufficiently offline it will be tested on site to ensure that the new communications software works as expected and that the analysis produces improved cut results compared to the existing analysis.

This process will allow for the yield benefits of the upgrade to be incorporated into the cost-benefit analysis of the LEAP IV system, to be provided by Greenleaf Enterprises Pty Ltd.

While the upgrade was tested multiple times at a production site, there were operational software bugs that affected the ability to collect large amounts of relevant data.

3.3 Cost-benefit analysis methodology

3.3.1 Data Quality Control

There is always a range in accuracy and performance within manufacturing environments, particularly where a biological product like a carcase is involved. Manual processes will always show a range in variation as will automated process (hopefully to a lesser degree). This variation warrants a range in value or cost to be provided rather than a single number. For each scenario, ranges are reported by lower (left column) and upper (right column) confidence intervals. Range in system accuracy is of interest with narrow variation increasing the ability to control and refine the process.

3.3.2 Cutting Yields

Market requirements determine the location of cutting lines for fabrication of lamb carcasses into primal cuts. All other processing that occurs on the lamb carcasses is based around these cutting lines. If the initial primal cutting lines are not accurate, then this will have an impact on the ability to process the product according to market specifications. Ultimately costs will be incurred through discounts if inaccuracies in the cutting lines don't allow product to meet market specifications. As such, the accuracy of the cutting lines was an important part of the data collection phase. This subsection gives consideration to the measurement of accuracy levels observed with the manual cutting system, and the quantification of costs incurred because of inaccuracies.

The middle machine receives the primal from the primal cutting robot and conducts the following processes on the middle:

1. Removal of spinal cord.
2. Separation of rack from short loin (optional).
3. Removal of flaps.
4. Chine bone removal.
5. Splitting of rack or full loin (optional).

3.3.3 Operating and OH & S costs

The operational and Occupational Health and Safety (OH & S) data collected was as follows:

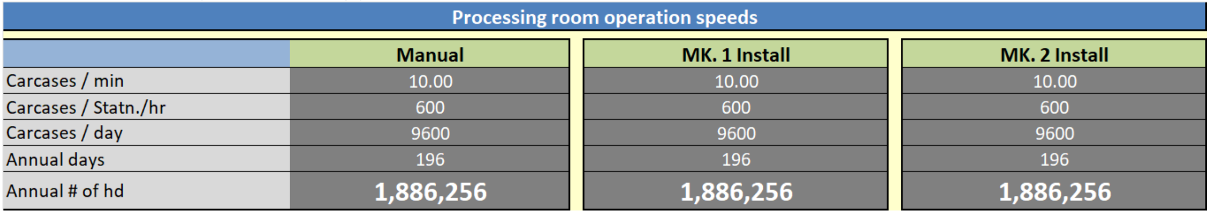
- Staffing levels per shift.
- Cost per hour for staff and AQIS officials.
- OH & S claim costs over the last 10 years.
- Power costs associated with bandsaws; and
- Maintenance costs of bandsaws.

These costs have been used to calculate average operating cost reduction for each area through the installation of the automated cutting system.

3.3.4 Fixed Model Drivers

To establish the dollar value per head for each cost and benefit, the production numbers in Table 1 were used. The table compares throughput under the automated system to the manual process for both the ex-ante estimate and the ex-post-performance of the system. Importantly, ex-post throughput was intentionally kept constant with the manual, as throughput benefits are not the focus of this ex-post report. This consistency and accuracy of the MK 1 and MK 2 systems are the key drivers of benefit within this report. However, the MK 2 system failed to provide the upgrade in benefits that were expected at the on-set of the project due to software integration issues.

Table 1: Calculation used for determining production volume baseline.



Processing room operation speeds

	Manual	MK. 1 Install	MK. 2 Install
Carcases / min	10.00	10.00	10.00
Carcases / Statn./hr	600	600	600
Carcases / day	9600	9600	9600
Annual days	196	196	196
Annual # of hd	**1,886,256**	**1,886,256**	**1,886,256**

4. Results

4.1 Demonstrate the improvements in vision analysis accuracy from the Rack software system upgrade.

4.1.1 Rack analysis improvements

Despite several iterations of improvements in calibration and software analysis there remains sources of error in the software systems. The proposed upgrade to the Rack analysis involves the implementation of a AI technique for the locations of the eye meat on the product face, as well as the rib tracing.

Vision analysis – Source of Error

The assessment of the potential improvements made by the new implementation of the Rack system, was done by inputting existing images into the new software package.

Rack analysis improvements

This is the same product analysed by the current system on the left, and the upgraded system on the right.

In the new system the image is rectified, to make the cut face of the meat appear flat in the plane of the image, while in the old system the image is colour balanced, which is why they appear different. While the corner of the eye meat was failed to be identified in the original system, the new system correctly finds the corners.

The initial model was trained on 3131 images from a Melbourne-based processor where the upgrade kit was intended to be deployed. However, ultimately the test site was shifted to a New South Wales-based processor, and this required gathering an additional 1000 images from the New South Wales site to fine-tune the model.

Once the model was trained, it was compared to the existing analysis on the test set of images, i.e., images that neither system had ever been exposed to before. Two hundred test images were set aside for this purpose, all from the New South Wales site. The existing analysis and the upgraded analysis were then both compared to the manually marked data.

Because the cut position is determined by a combination of the eye meat location and the flap tracing, the distance from the manually marked data differs based on the cut lengths. The results below show the errors found in the existing and upgraded analyses for the 25mm, 50mm, 75mm, and 100mm rack cuts.

Table 2: Comparison of 25mm rack errors on test set.

25mm Rack	**Existing Analysis**	**New Analysis**
Mean Error (mm)	3.4mm	1.2mm
Median Error (mm)	3.1mm	1.0mm
Standard Deviation (mm)	2.5mm	1.0mm
95th Percentile (mm)	7.0mm	3.0mm

Table 3: Comparison of 50mm rack errors on test set.

50mm Rack	**Existing Analysis**	**New Analysis**
Mean Error (mm)	3.1mm	1.3mm
Median Error (mm)	3.0mm	1.0mm
Standard Deviation (mm)	2.4mm	1.0mm
95th Percentile (mm)	6.7mm	3.3mm

Table 4: Comparison of 75mm rack errors on test set.

75mm Rack	**Existing Analysis**	**New Analysis**
Mean Error (mm)	2.9mm	1.3mm
Median Error (mm)	2.4mm	1.1mm
Standard Deviation (mm)	2.5mm	1.0mm
95th Percentile (mm)	6.4mm	3.5mm

Table 5: Comparison of 100mm rack errors on test set.

100mm Rack	**Existing Analysis**	**New Analysis**
Mean Error (mm)	6.9mm	1.4mm
Median Error (mm)	7.1mm	1.3mm
Standard Deviation (mm)	3.5mm	1.0mm
95th Percentile (mm)	12.6mm	3.1mm

The most common rack length at the processor's site is the 75mm rack and for this the new analysis has a mean error that is 55% less than the existing analysis, at 1.3mm as opposed to 2.9mm for the existing analysis. The 100mm rack cut shows the greatest improvement with a mean error reduction of 80%, however, the improvements seen in the 100mm rack cut are markedly higher than for the other cuts, owing to the increased distance from the eye meat and difficulties with the existing analysis properly tracing the rack flaps at the ventral end.

Importantly, the standard deviation of the new analysis is significantly better than existing analysis, indeed for every cut the standard deviation of the new analysis is less than 50% of the existing analysis. This reduction in mean error and standard deviation of error represents a significant improvement on the existing analysis, with the potential for millimetres of yield gain per product as well as a reduction in any re-working of product.

Histograms for the rack cuts are shown below with the 95th percentils shown in vertical lines in order to better visualise the improvements offered by the new analysis.

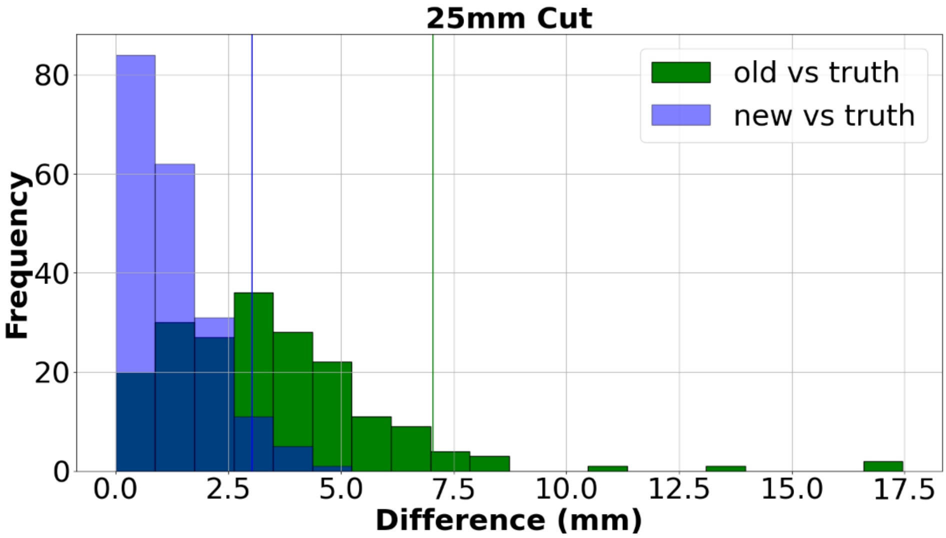


Figure 3: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 25mm rack flap cut. The vertical lines show the 95th percentiles for each analysis.

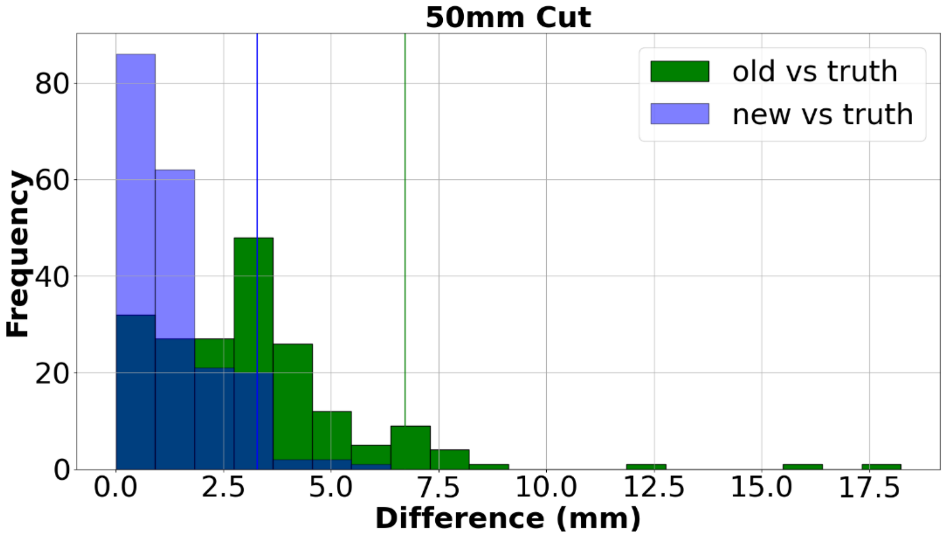


Figure 4: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 25mm rack flap cut. The vertical lines show the 95th percentiles for each analysis.

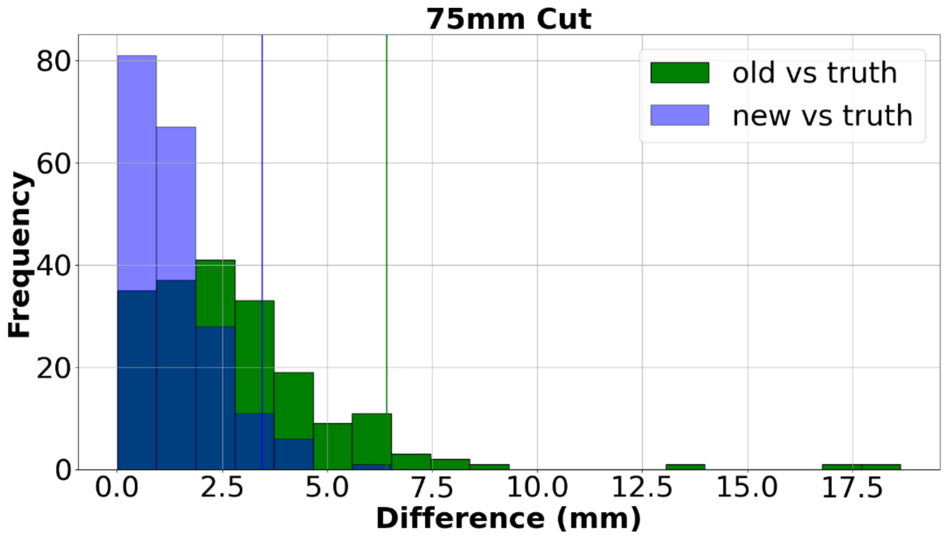


Figure 5: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 25mm rack flap cut. The vertical lines show the 95th percentiles for each analysis.

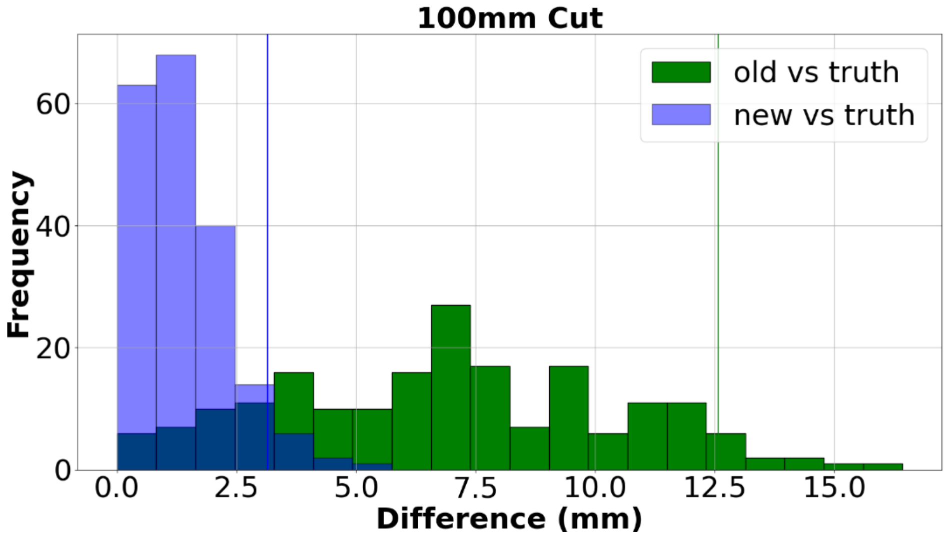


Figure 6: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 25mm rack flap cut. The vertical lines show the 95th percentiles for each analysis.

A key metric of interest in the results above is the 95th percentile. The 95th percentile is used to specify the accuracy of Scott machines for any given cut. For example, the rack flap cut is currently specified as 95% of products within the range of ±7mm. This aligns well with the results of the existing analysis, where the median value across the four cut lengths for the 95th percentile is 6.85mm. For the new analysis the median value across the four cut lengths for the 95th percentile is 3.2mm. In terms of machine performance, these results show the new analysis to be more than twice as accurate as the existing analysis.

4.1.2 Loin analysis improvements

The loin analysis improvements are fundamentally similar to those of the rack analysis improvements. As with the rack flap cuts the loin flap cuts are measured relative to the eye meat of the product and traced down the flaps. Likewise, most analysis failures are due to the eye meat of the product being incorrectly identified or the flap of the product being incorrectly traced.

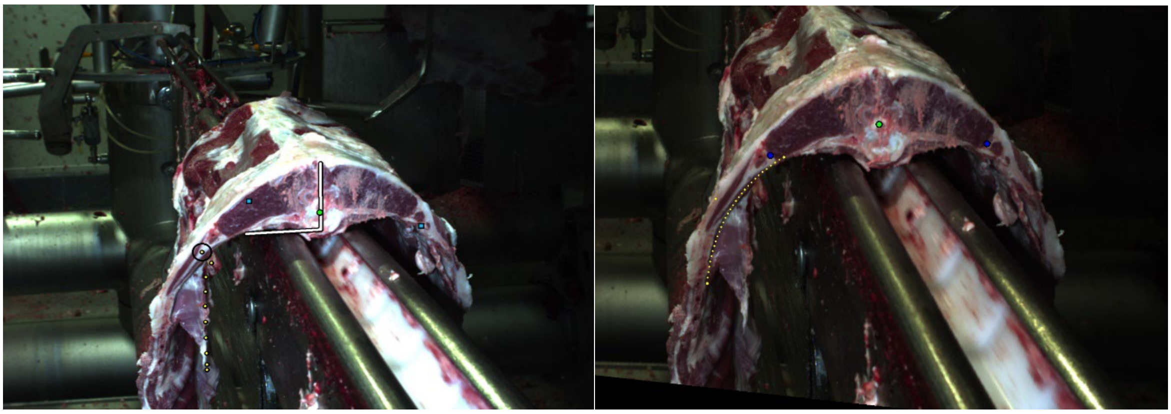


Figure 7: An example of the improvements in the analysis. The left-hand side shows the eye meat (blue) being found incorrectly. Likewise, the flap tracing (yellow) has traced the hanging piece of diaphragm rather than the true flap. While the new analysis has correctly identified the eye meat on both sides and has correctly traced the flaps.

As shown in Figure 7 the new analysis can correctly identify the eye meat in situations where the existing analysis has failed. A point that is especially relevant to the loin is that the flap tracing in the new analysis appears to be more robust to hanging diaphragm on the product. The existing flap tracing analysis struggles in the presence of diaphragm, which can affect the longer loin flap significantly. Another example of the improved flap tracing is shown in Figure 8.

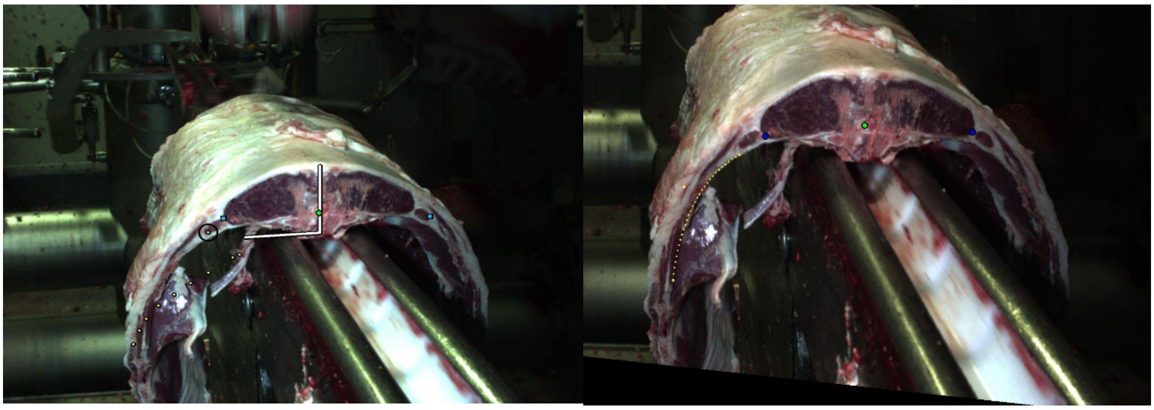


Figure 8: Here the existing analysis (left-hand side) has failed to accurately trace the flaps due to the presence of hanging diaphragm. However, the new analysis (right-hand side) has accurately traced the flap and has ignored the hanging diaphragm.

The results of the improved analysis are shown below in Table 6 - Table 9. As with the rack analysis, the loin analysis is evaluated on a test set of images that the model has not seen before. For comparison the performance of the existing analysis is provided alongside the new analysis results.

Table 6: Comparison of 25mm loin errors on test set.

25mm Loin	**Existing Analysis**	**New Analysis**
Mean Error (mm)	8.0mm	2.5mm
Median Error (mm)	6.7mm	2.1mm
Standard Deviation (mm)	6.75mm	2.1mm
95th Percentile (mm)	21.0mm	6.7mm

Table 7: Comparison of 50mm loin errors on test set.

50mm Loin	**Existing Analysis**	**New Analysis**
Mean Error (mm)	5.3mm	2.5mm
Median Error (mm)	4.0mm	2.1mm
Standard Deviation (mm)	4.8mm	2.0mm
95th Percentile (mm)	14.3mm	6.3mm

Table 8: Comparison of 75mm loin errors on test set.

75mm Loin	**Existing Analysis**	**New Analysis**
Mean Error (mm)	5.5mm	2.6mm
Median Error (mm)	4.2mm	2.1mm
Standard Deviation (mm)	5.0mm	2.0mm
95th Percentile (mm)	14.9mm	6.3mm

Table 9: Comparison of 100mm loin errors on test set.

100mm Loin	**Existing Analysis**	**New Analysis**
Mean Error (mm)	8.3mm	2.5mm
Median Error (mm)	7.7mm	2.1mm
Standard Deviation (mm)	5.4mm	2.0mm
95th Percentile (mm)	17.9mm	6.0mm

As shown above the new loin analysis represents a large improvement over the existing analysis. Not only is the average (whether mean or median) error significantly improved, from 4–8mm to 2-3mm, but the standard deviation of the new analysis is also reduced by a factor of 2-3. This allows for a much more consistent product than possible with the existing analysis. The most common cut for the processor's site is the 100mm loin and for that cut the new analysis reduces the 95th percentile by a factor of almost three, or a reduction of 11.9mm.

To get a more complete view of the errors involved in the loin analysis comparison the histograms of errors are shown below.

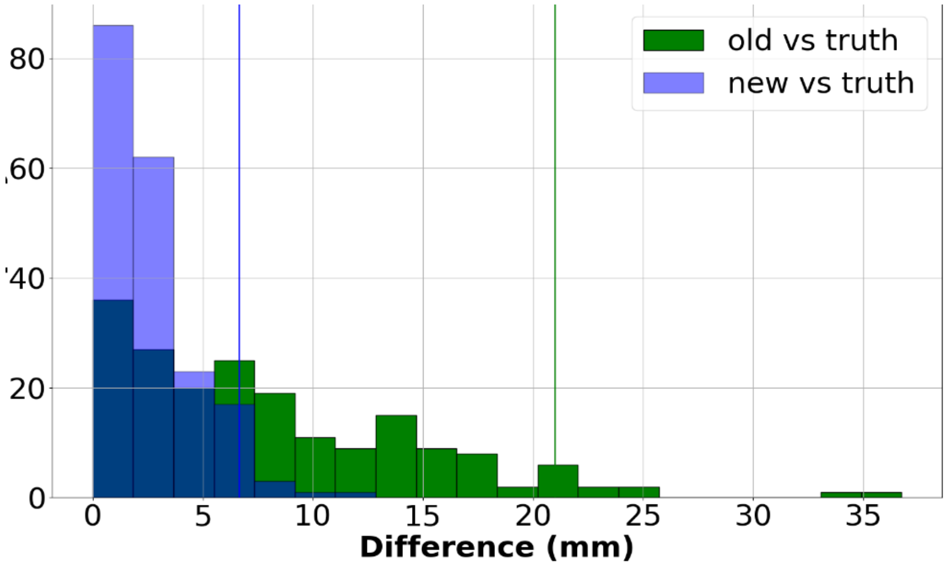


Figure 9: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 25mm loin flap cut. The vertical lines show the 95th percentiles for each analysis.

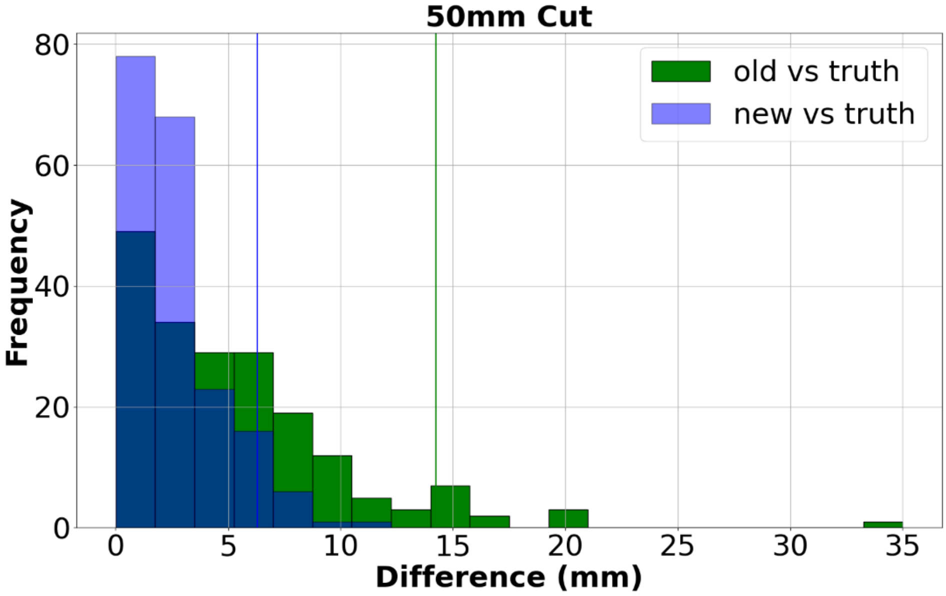


Figure 10: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 50mm loin flap cut. The vertical lines show the 95th percentiles for each analysis.

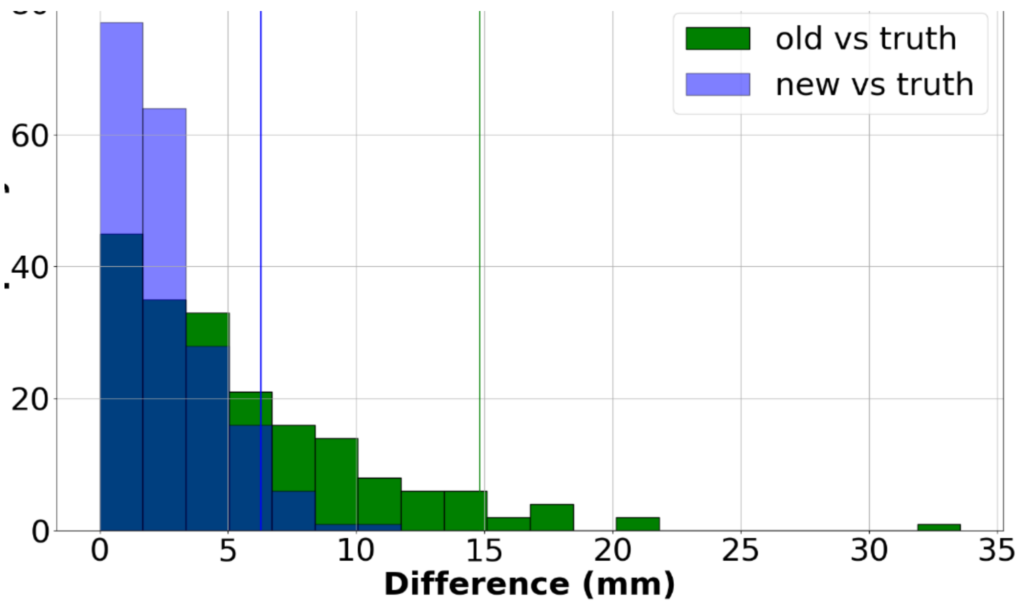


Figure 11: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 75mm loin flap cut. The vertical lines show the 95th percentiles for each analysis.

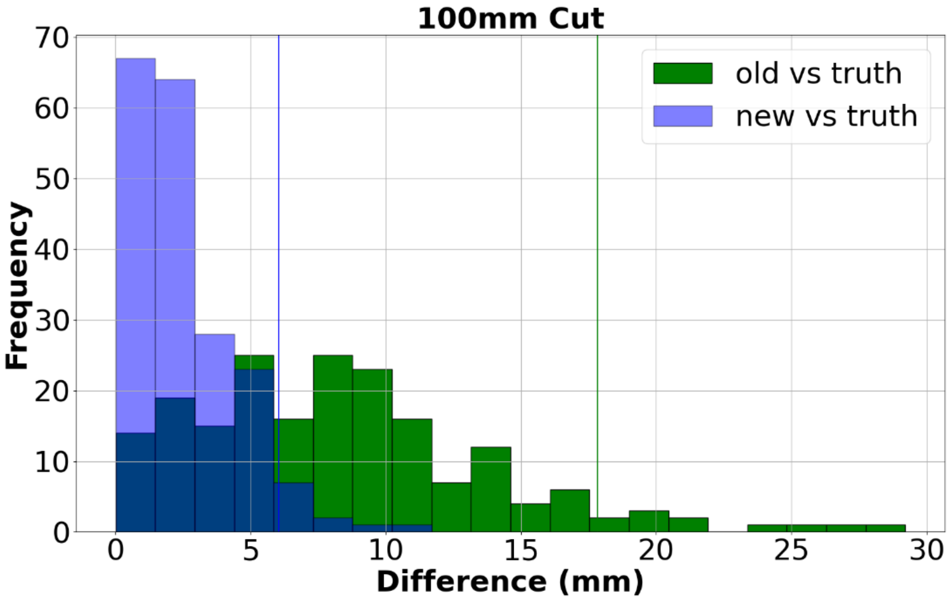


Figure 12: Comparison of the errors in the new analysis (blue) and the existing analysis (green) for the 100mm loin flap cut. The vertical lines show the 95th percentiles for each analysis.

4.1.3 Develop and test the upgraded 3D Loin product image capture and analysis, in parallel with existing LEAP system on site

A major source of error for the loin product in the existing vision system is not a failure to locate the eye meat, (although this does account for some of the failure modes), but instead an inaccurate product position on the rail. The existing analysis calculates the product position based on the estimated length of the loin from x-ray data. However, there are inaccuracies in the x-ray length estimation. Additionally, the product can move on the rails so that the product is further along the rail than expected.

An example of an incorrect product position is shown in the left-hand image of Figure 13.

Product position – Source of Error

Figure 13. Currently the position of the front face of the product at camera 3 (half camera) is calculated from x-ray data and provided to the middle analysis. If this is incorrect (and it is incorrect by up to ±20mm) then the image appears like the left-hand image where the projected axes do not align with the featherbone and the bottom of the product (see the right-hand side for where the axes should be). This error means that the pixel to mm calculation is off and so even if the eye meat is found correctly then the cut position will still be incorrect.

A RGBD camera was chosen to provide colour images and direct measurements of the product position, thereby eliminating any x-ray errors in length and errors due to the product sliding along the rails.

The camera system was installed in a temporary capacity on site at Alliance Lorneville, in a production room where a 2021 LEAP installation was operating in full production.

As to not disrupt that production the camera installation was done in parallel with the existing vision system.

Development of Loin System

The development in this Milestone involved the image and data capture of a significant number of products utilising the RGBD camera, followed by the training and tuning of the AI software. The dataset was captured on an existing site with the RGBD camera and software running in parallel with the existing system.

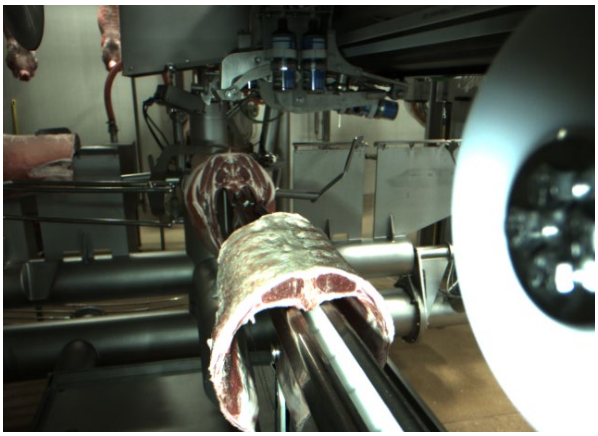


Figure 14: Image from the RGBD device, during the in-production test at Alliance Lorneville.

It was necessary to collect a dataset of a reasonable size to be able to train and test a new AI analysis on. Over 5000 images were collected on site. Once rejects and dry cycle images are removed, there should be a data set large enough to produce a high-quality training result.

The Camera can produce a two-dimensional RBG (red, green, blue) image, with added depth information as a 4th channel, making it RGBD (red, green, blue, depth). It can also produce a point cloud, but for the purposes of this work, we believe that the depth information would suffice and trying to implement an analysis using the point cloud would add complexity but be no more effective in finding the meat face.

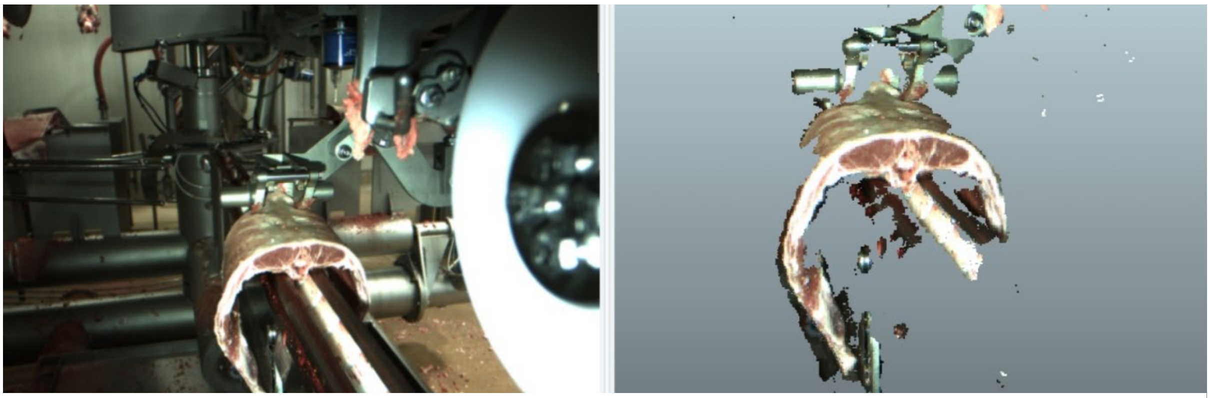


Figure 15: Side by side taken from the RGBD Camera to test the camera communications.

On the left is the 2D image from the camera, and on the right is a filtered 3D reconstruction including the meat face and some of the rail. This shows the camera can produce a reasonable quality filtered image for analysis.

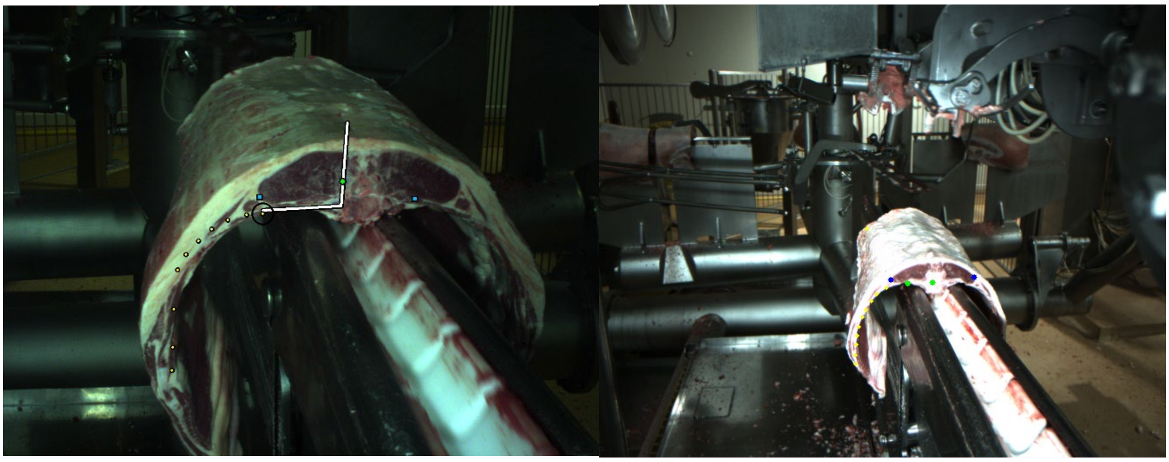


Figure 16: The left-hand side image shows the existing analysis using the provided product position, which shows the face of the loin being further forwards than expected. The right-hand side image is from the and has directly measured the product position.

Figure 16 shows the existing analysis (left-hand side) and the analysis from the (right-hand side). The green point in the centre of the product indicates where the spinal cord hole should be, note that the existing analysis has the point on the left-hand side of the spinal cord hole which indicates that the product face is further along the rail than expected. Note in the new analysis that the spinal cord hole indication (the right-hand green dot) is in the centre of the product.

The existing system (using the RGB cameras) uses the known positions of the camera and the product rail, and a calibration block.

Because of the costs of the RGBD camera, another approach was taken to see if the accuracy of the system could be improved without changing the camera used for the analysis. This would allow a pure software upgrade for existing sites which, once thoroughly tested, could allow for a much quicker upgrade with significantly less downtime for the processor.

Because the position of the rail is well known in both the 3D coordinate system and the 2D pixel coordinate system, if the pixel coordinates of the front face of the product on the rail are able to be accurately determined then the accuracy of the loin flap cut would be greatly improved without the requirement for a new expensive camera and retrofit.

The approach for determining the product position with the RGB camera was to manually label product position on the rail. Once this data was collected AI technique was trained to predict the product position based on the initial image. The results for the AI technique used for the New South Wales site are given in Table 10.

Table 10: Comparison of product position errors from x-ray derived position and AI derived position.

	X-ray Derived Position Error	**AI Derived Position Error**
Mean Error (mm)	30.1mm	4.4mm
Median Error (mm)	29.8mm	3.7mm
Standard Deviation (mm)	10.7mm	3.6mm
95th Percentile Error (mm)	46.6mm	11.4mm

While the errors seen in the existing x-ray derived position shown in Table 10 seem very large, it is important to note that due to the orientation of the camera even a relatively significant error (say 30mm) in the product position can result in a much smaller movement of the final cut position (~4mm). This is because the camera primarily looks along the rail, the more the camera looks along the rail, the less the product position along the rail will affect the pixel position where the product meets the rail. However, the reduction in error to around 4mm on average was only around twice the error of the RGBD camera (2mm) and the reduction in complexity and cost of the upgrade made sense for the project to pursue this method of determining the product position.

In the historgram below it is clear that the derived product position represents a significant improvement, not just on average but especially for the maximum error. With the maximum error of the derived product position at approximately 16mm, the maximum error of the x-ray derived product position is more than 70mm, representing an improvement of more than a factor of four.

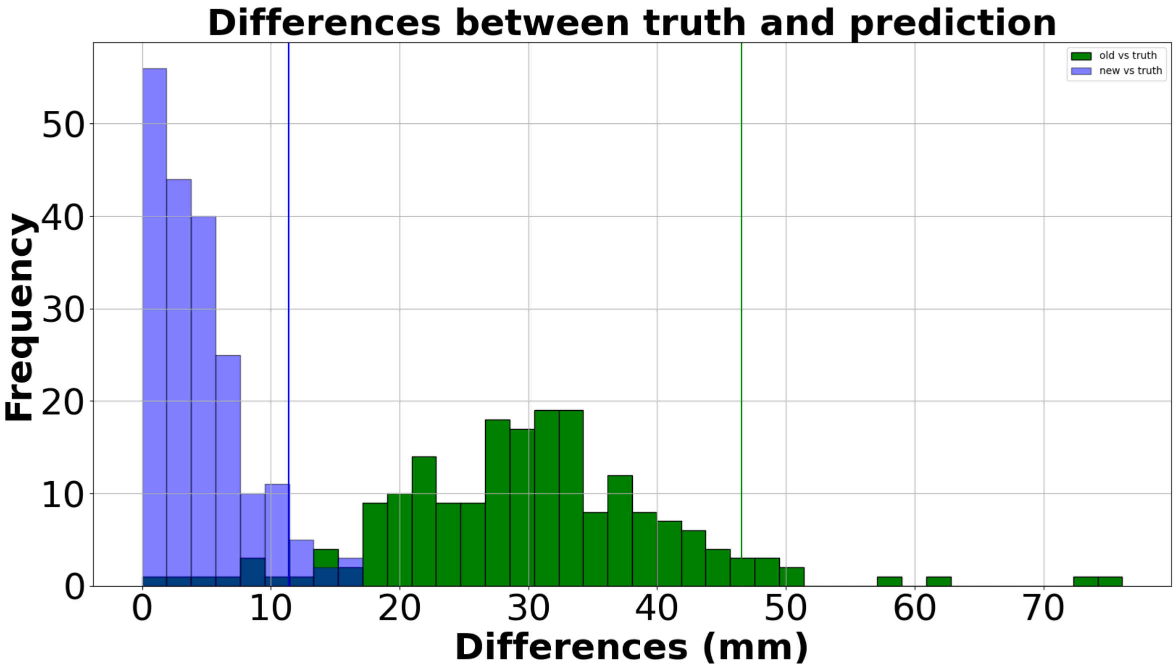


Figure 17: Comparison of errors in x-ray derived product position (blue) and AI technique derived product position (green). The 95th percentiles of both are shown as vertical lines.

While the x-ray derived product position is relatively accurate on the meat rail, error is introduced in the estimate once the product has been laid down horizontally, once the product has been separated into the rack and loins, and once the product has been pushed horizontally along the rails. Instead of using this x-ray derived product position the AI technique derived product position provides a much more accurate product position without requiring the installation of new expensive hardware and the reduction in image resolution thereby incurred.

4.2 Deployment of Middle Vision Upgrade kit on site

The Middle Vision kit upgrade software was installed on site at an Australian processor. As mentioned above the majority of the work required for the project consisted of offline testing of the analysis to ensure that the new analysis would be an improvement on the existing analysis.

Due to the significant differences in how the upgraded software operates new communication software had to be written for the PC <-> PLC communications. This was intended as a relatively small portion of the project, with the possibility of tidying up some known communication limitations.

Due to the continual improvements of the systems, as well as site-specific accommodations the communications structure of the PC <-> PLC communication differ from site to site. Therefore, to ensure the system functions correctly, it must be tested with the communications structure running at the relevant site. While the differences in structure are relatively small, they are sufficiently large to introduce faults or rejects on the machine, if not properly taken into account.

4.2.1 Bench testing of communications software (Melbourne site)

The new communication software was bench tested at the Scott Dunedin site with a PC, camera, and PLC running the communications software that is currently running on site at a Melbourne-based processor.

Issues were identified, fixed, and those fixes tested, as expected in the testing of any new software.

Once the PC and PLC were communicating successfully with mock product data the new software was uploaded to the Melbourne processor in preparation for dry cycle testing.

4.2.2 Dry cycle testing of communications software (Melbourne site)

After bench testing, the next stage of trialling new software on site is to test the software in dry cycle, i.e., running without product. In dry cycle there is no product physically present, but the communications protocol is the same and instead of individualised cut data, default cut data is sent. Dry cycle testing allows more practical testing of the communications software for example taking into account network traffic and hardware timings but without risking incorrect cuts on customer's product.

A window of time was available for dry cycle testing at the Melbourne site where a Scott staff member was on site to run the machine outside of production. The new software ran in dry cycle and while most aspects ran as expected, there was an issue with the timing of the cut result request which caused a fault and had to be found and fixed. Unfortunately, by the time the issue had been identified and fixed, the window of time with a Scott staff member on site had closed.

At the time Scott was installing and commissioning a new system at a New South Wales-based processor and the decision was made to continue the software testing at this site, to guarantee Scott staff presence and more easily facilitate machine access both during and outside of production.

4.2.3 Bench testing of communications software (New South Wales site)

To capture the differences in communications structure for the new site the communications software was re-tested at Scott Dunedin with the PC, camera, PLC setup and the communications structure running at the New South Wales site. The software passed the bench test with the new communications structure with a few site-specific alterations.

An element of added complexity was that the cameras used in the LEAP IV Middle systems have become obsolete and the replacement model from the manufacturer has a different software interface and aspect ratio. This necessitated retraining a new neural network for the new aspect ratio which delayed testing on site. See 4.1.1 where we talk about training the New South Wales model.

4.2.4 Dry cycle testing of communications software (New South Wales site)

With Scott staff on site for machine commissioning, machine access outside of production was easy to arrange and Scott staff were able to run the machine in dry cycle and assist with any problems as they emerged. Some small communications issues arose during dry cycle testing, but they were relatively quick to identify and fix due to the availability of the machine outside of production.

Offline testing showed the product at the New South Wales was more variable than the product at the Melbourne site and after initial dry cycle commissioning was finished the model required more data and more tuning to reach the same level of accuracy as the Melbourne model. While the model was being retrained and tested other software was written and implemented to more confidently determine if there was a product in the image or not. Additionally, the logging of the software was upgraded to assist in future troubleshooting.

4.2.5 Production cycle testing of communications and analysis software (New South Wales site)

Machine access outside of production was relatively simple to arrange while Scott staff were on site. However, access was more difficult to arrange during production as, while the machine was technically in the commissioning phase, the machine was processing significant quantities of product per shift so any disruption to the machine during production had to be minimised. Additionally, any damage to product due to analysis errors or incorrect rejecting would directly impact the customer and had to be minimised at all costs.

The first test of the new software in production rejected all product in the test. The cause of this was found to be due to differences in the cut configurations between the Melbourne site and the New South Wales site.

Once the cut configuration issue was resolved, a second test in production was run which resulted in most of the product being rejected. This was due in part to the model underperforming and in part due to the product range being larger than expected. The larger than expected product then failed analysis checks which were in the software to determine if the analysis results were reasonable or were likely failures, this caused a significant number of correctly analysed product to be incorrectly rejected as failures.

To address the rejects in the previous test, the model was retrained to capture a larger variety of the product range at the processor. Additionally, the sanity check limits were expanded to represent the true size range likely to be seen at the New South Wales site. These changes were tested offline with the images from the previous test and were shown to address all products seen in the test.

With the model and product limits improved a third test was run at the New South Wales site. Unfortunately, a large number of the racks were incorrectly rejected, and the software was quickly reverted to the existing analysis so as to minimise the disruption and product rework required for the processor. In this case, the cause was identified to be a change in lighting that affected the model that was responsible for identifying if a product was present or not, i.e., with the new lighting the model was incorrectly flagging most products as an empty image.

The model responsible for identifying the presence of a product was retrained with the new lighting, as well as image augmentation that should cover any further changes in lighting, within reason. A fourth production test was arranged with the New South Wales processor while Scott commissioning staff were still on site to assist with running the test. Unfortunately, many of the racks were rejected again.

With Scott commissioning staff leaving the New South Wales site, and other issues taking priority for the customer the decision was made to regroup at Scott Dunedin and acknowledge the production tests as a negative result.

While the production tests produced a negative result, the result was not due to a failure of the new analysis to achieve a higher accuracy than the existing analysis. Instead, the development of the peripheral systems for the analysis, i.e., communications, part detection, product variation limits, proved to be the point of failure.

The analysis results seen in the previous sections provide significant increases in accuracy compared with the existing analysis. Because of this, Scott will continue working with the new analysis and with the build and commissioning of a new LEAP IV machine currently taking place, the opportunity will be taken to thoroughly test the new analysis and peripheral software while the machine is in the Scott factory. The intention is that this will allow free access to the machine and an opportunity to test new software fixes quickly, without risking a customer's production. This system is currently in the advanced stages of the build and will allow for software testing and commissioning in August 2023.

4.3 Updated Cost-benefit analysis

The main value proposition for the installation of the lamb middle cutting system is categorised into savings in the following areas:

- Increase in yield.
- Increase in labour productivity.
- Reduction in operational costs.
- Reduction in work cover premiums.

The cost savings will be discussed in detail in the following section.

4.3.1 Benefits

Improvement in accuracy of cutting lines over manual was observed for all cuts. Different customer specifications required different distances of cutting lines from anatomical locations in most cases. These variations were taken into account when calculating value benefits. The dollar benefit reflects distribution across product specifications and has been analysed to account for different tail lengths, yield of each sub primal and associated cut sale price per kg.

4.3.1.1 Spinal Cord Removal

The removal of the spinal cord is conducted by the automated system. Data collection confirmed that there was no difference observed in the effectiveness of the spinal cord removal between the manual and automated system. Therefore, the only benefit of the automated system on the removal of the spinal cord is the reduction in labour requirements for the boning room. One labourer was saved across this task and bone dust scraping.

4.3.1.2 Shortloin Pair - Flap Removal

The variation observed in the removal of the flap from the shortloin pair has a substantial effect on the value of the shortloin pair. When the cut is conducted in a negative direction (shorter tail), product is lost from the shortloin pair as trim. Cutting variation is less in the ex-post results than observed during manual trials which makes it easier to adjust and optimise cutting lines for accuracy and increased value than was possible with manual processes. The benefit would be greater if the plant was producing more cap-on racks.

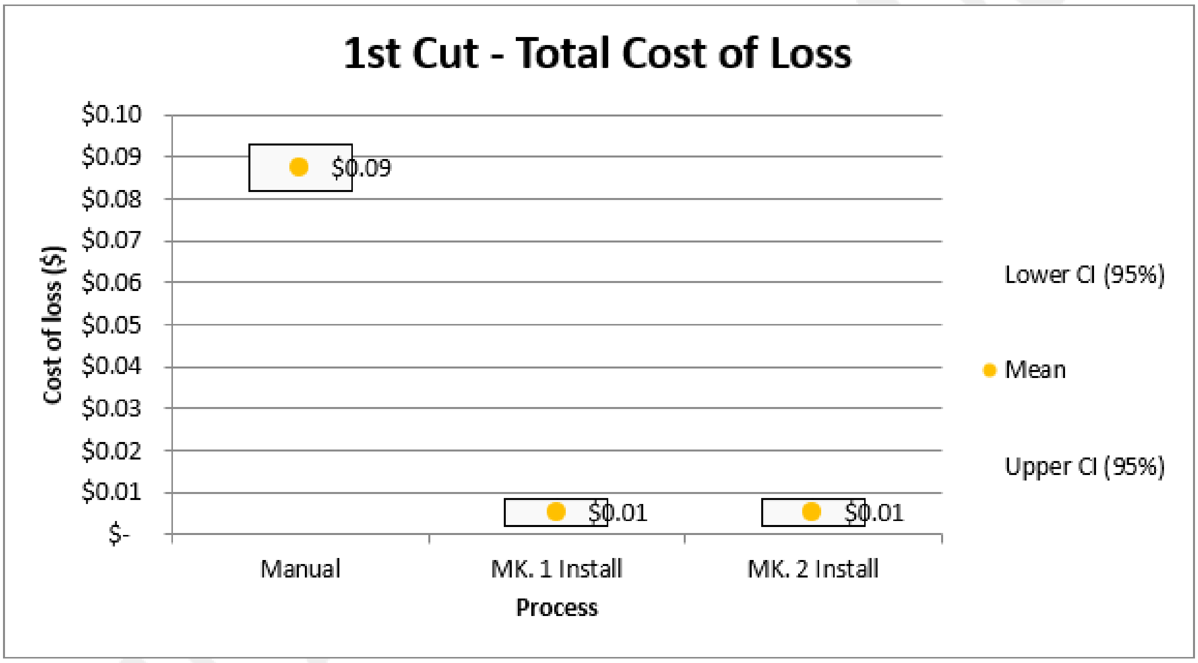


Figure 18: Value loss per carcasses for removal of flap from the shortloin pair.

4.3.1.3 Rack Flap Removal

The variation in the removal of the flap from the Rack can have a considerable affect in the value of the product sold. The value of loss attributed to un-frenched products was calculated to incorporate the total value of loss for the cap, intercostal and bone.

The methodology for costing frenched product has changed slightly when compared to previous studies on the primal cutting system. The costing method of frenched product in this ex-ante included the value of intercostal as frenched rib length changes the frenching length as a result of automated frenching.

The combination of the 7 different cutting specifications were used to calculate the value of loss attributed to the savings as shown in Figure 19. The yield benefit across these specifications has caused substantial reduction in the cost of loss between manual and the automated performances in Figure 19.

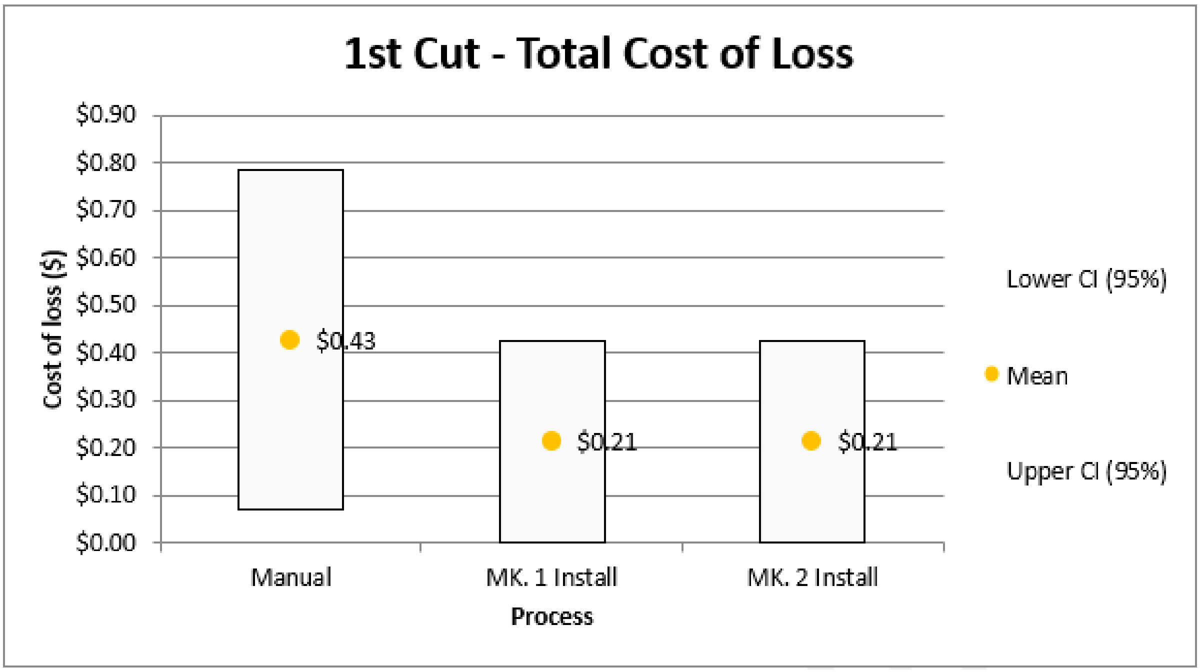


Figure 19: Total cost of loss for the removal of flaps from racks.

4.3.1.4 Rack lost to Shortloin Pair

The variation in the cut between the shortloin pair and rack required 4 measurements to be completed to estimate variation arising from the manual operator. The collection methods of the following measurements can be observed in section 3.2.1.

- Angulation of the cut.
- Number of ribs.
- Millimetres over the ideal location of the cut.
- Length of last partial rib from the vertebrae.

Angulation

The angulation of the cut mainly affects the amount of bone and intercostal sold as rack or left as render and trim. The value increase for this cut was minimal as operators accurately line up the angle when cutting the ribs. The variation can be seen in Figure 20 which shows the grams from the rack to render and shortloin pair.

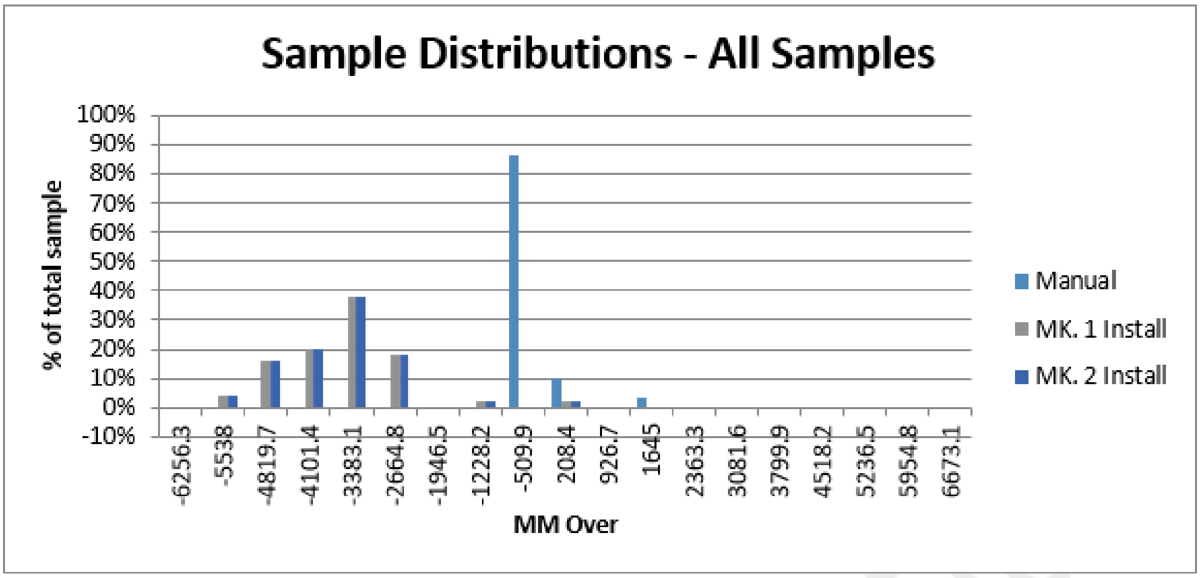


Figure 20: Square centimetres of meat lost from the rack to the shortloin pair as a result of the angle and location of the cut.

The total value of loss per head demonstrated by this cut is between $0.64 and $0.70/hd according to ex-post results.

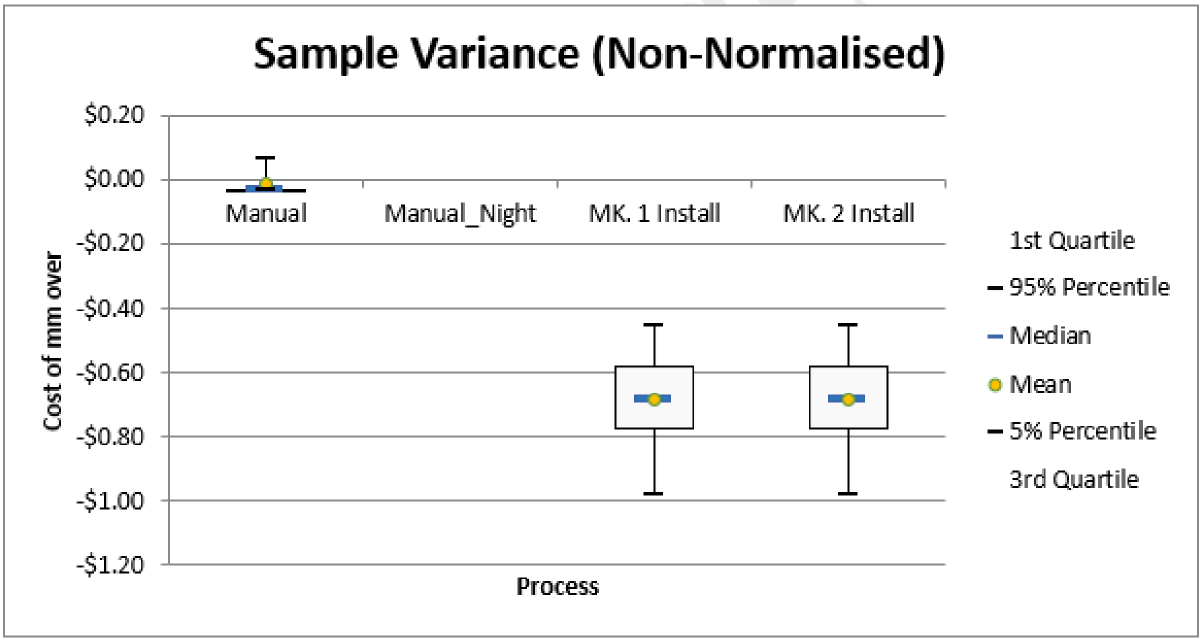


Figure 21: Total value of loss due to the variation in the angle of the shortloin pair to rack cut.

Number of ribs

There was very minimal value attributed to the number of ribs on primals, as the manual operator was constantly cutting the right number of ribs.

The variations in costs shown below are only for an 8 rib rack which demonstrated the greatest variation of all the cutting specifications.

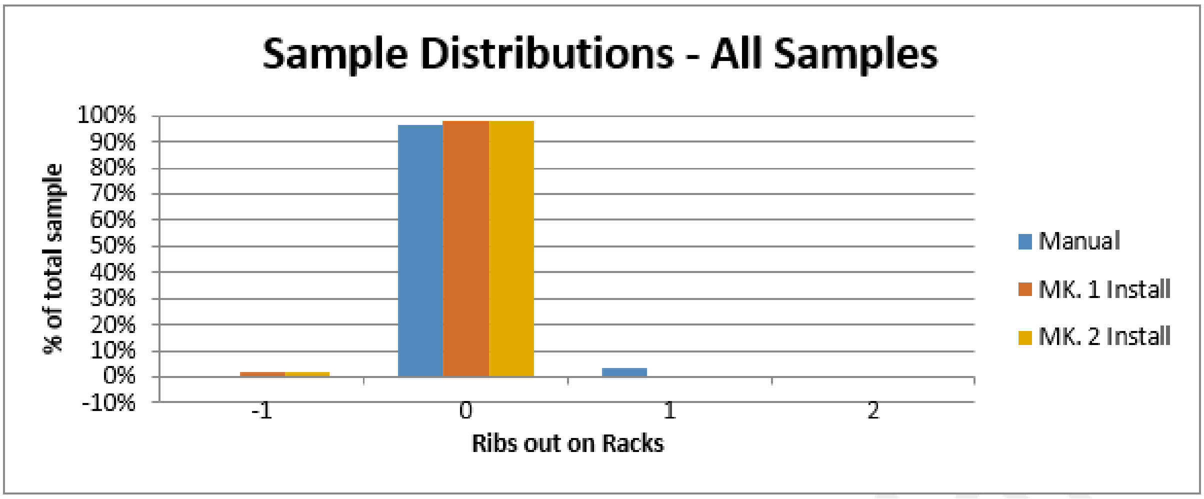


Figure 22: Value of loss associated with cutting the incorrect number of ribs, the peak at 0 is the ideal number of ribs and the "1" peak is 1 additional rib.

The two peaks in Figure 22 are representative of 0 and 1 ribs missing from left to right respectively.

Maximising weight and length of rack

The cut between the rack and shortloin pair tends to be cut too far into the rack. This 5 to 10mm over the cutting line accounts for most of the value of loss between the rack and shortloin pair and is a significant value opportunity, as seen in Figure 23. The ideal location for this cut is at the left-hand black line; this is where the 9th rib is slightly below the frenching line.

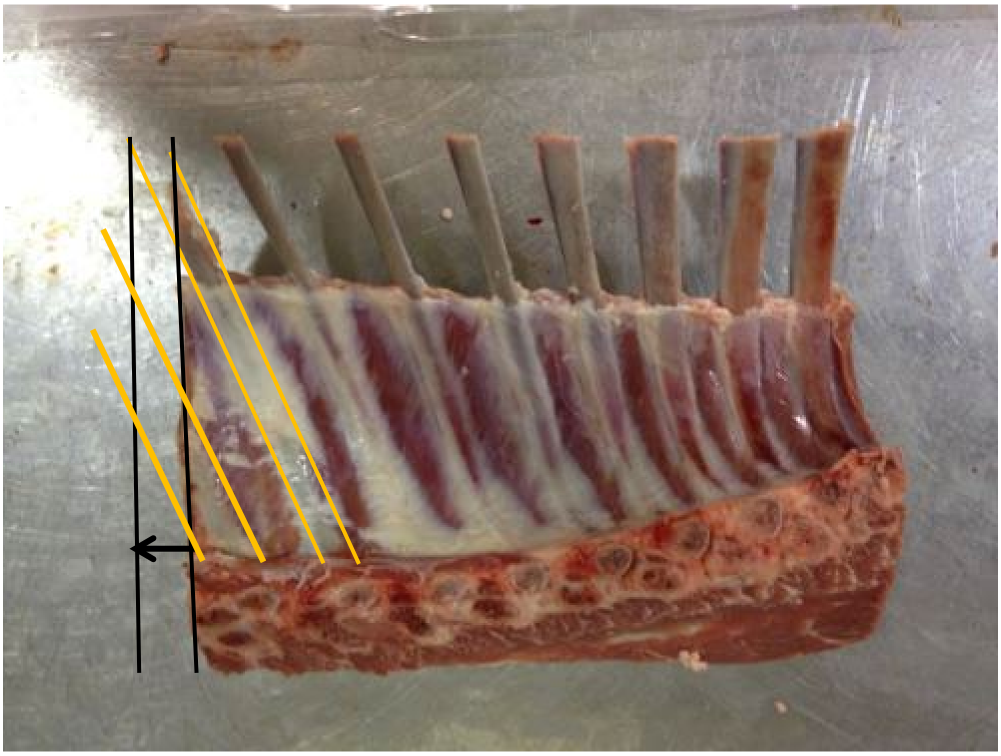


Figure 23: The Left-hand black line represents the length of product added to a frenched rack (move to number of ribs)

Optimising this cutting line represents the largest value opportunity of the automated system. The variation on this cut can be observed in Figure 24. The ideal location of this cut varies between cutting specifications. For 9 rib racks the maximum width from the 8th rib is 100mm whereas with a frenched 8 rib rack the maximum width is only 22mm. The value of loss was estimated by maximising the weight of the rack without causing a half rib to protrude into the frenching line.

The automated system demonstrated it was able to identify the ideal location of the cut on un-frenched products. The variation in value attributed to this cut for the 100mm frenched rack is shown in Figure 24.

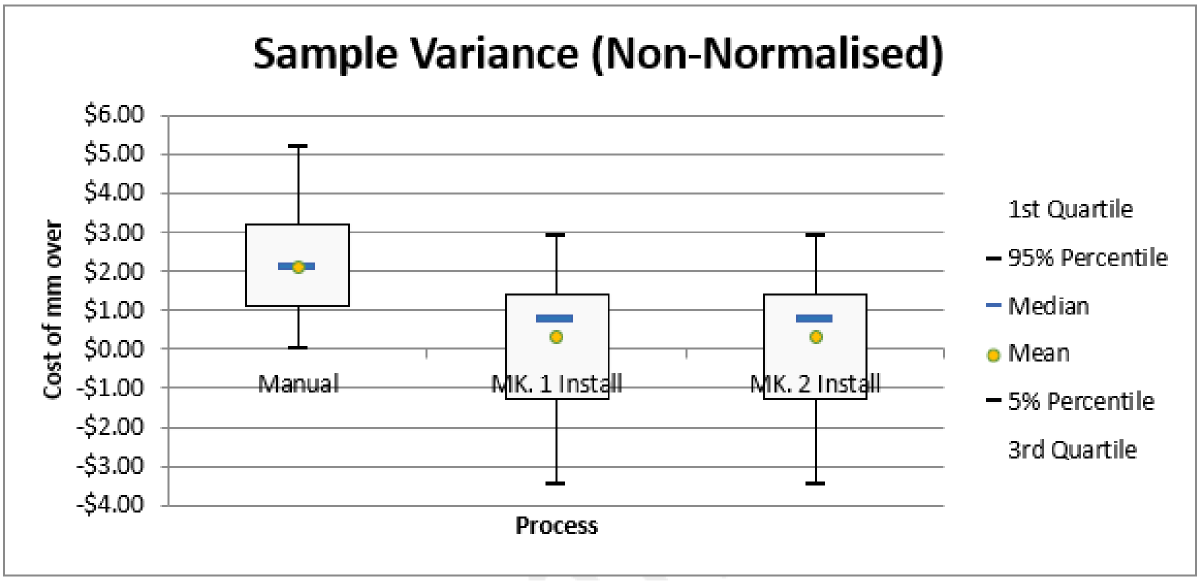


Figure 24: Value of loss attributed to maximising the weight of the rack from the shortloin.

Total Cut Value
The total value attributed to the cut between the Shortloin pair and the racks for all 7 cutting specifications can be seen in Figure 25.

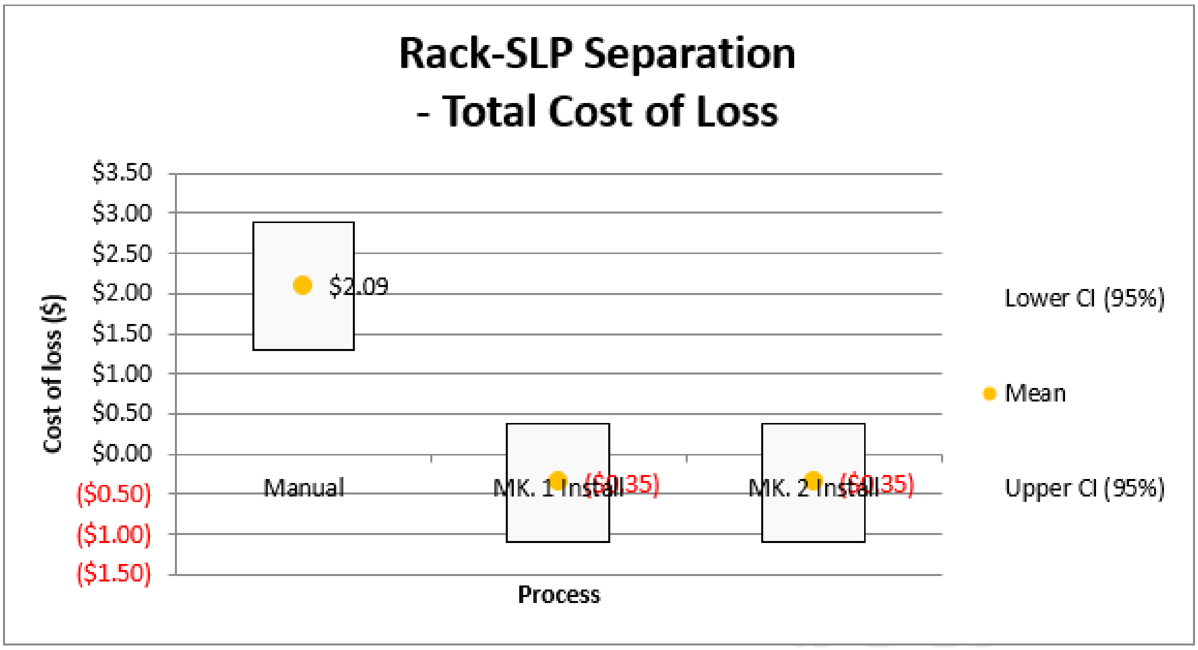


Figure 25: Total value of loss attributed to separating the shortloin pair and rack.

4.3.1.5 Chine Removal

The performance of the chining module for the middle machine was compared to manual bandsaw operations.

4.3.2 Reduced Bandsaw Dust

The use of bandsaws for cutting lamb results in bandsaw dust. This has two negative impacts; a) yield loss from the carcase and b) negative visual impact from the residual saw dust left on the surface of the product. An assumption was made that there would be a 90% reduction in sawdust with the automated cutting system.

4.3.3 Labour Savings (Reduced Staff)

Labour savings benefits can be categorised into two areas:

- Reduction in staff numbers as a direct result of automation
- Reduction in cost of labour per kilogram processed (increase in throughput was greater than increase in labour cost)

4.3.3.1 Reduction in staff numbers (Bandsaw operators)

Table 11 shows the number of staff required in each position of the boning and packing rooms per day for the manual process. Labour savings can be expected by the plant with the installation of the middle machine when considering throughput productivity gains.

Table 11: Labour savings achieved with the lamb middle cutting per shift.

Labour Savings per day			
	Number labour units required per day		
Task	**Manual**	**MK. 1 Install**	**MK. 2 Install**
Attec Saw	1	1	1
Rack Flap Sawmen	0	0	0
Knuckle (chine) Sawmen	1	-1	-1
Aitchbone Chop & Spliting Sawmen	1	1	1
AV Saw - B grade	1	1	1
Rotation Sawmen	1	1	1
Knife hand - Racks	3	3	3
Knife hand - SLP flap removal	2	0	0
Knife hand - Boneless Loins	3	3	3
Knife hand - Shoulder	5	5	5
Knife hand - Leg	5	5	5
Packroom	31	34	34
Total FTE's required	**66**	**63**	**63**
Total FTE's saved	**-**	**3**	**3**

4.3.4 Labour Savings (Increased Productivity)

The main driver behind increases in efficiencies for existing labour is a more consistent throughput of product through the cutting room. The manual processes rely on the bandsaw operator to set the speed at which the carcasses enter the boning belt. This rate varies depending on the bandsaw operator and carcase size. This either leads to labourers operating at less than optimum speeds or a build-up of product where operators are not able to keep up.

One of the main advantages of lamb middle cutting is the increases in the consistency of throughput which can improve flow.

4.3.5 OH & S Issues

Two main areas are identified where the automated primal cutting system will provide OH&S benefits. Firstly, eliminating the need for bandsaw operators to be lifting primals results in reduced sprain and strain injuries. Secondly, eliminating the need for operator interaction with a saw blade for the cutting of lamb primals typically reduces average OH&S claims.

4.3.5.1 Capital Costs

Equipment purchase price is based on prices supplied by the manufacturer. Note that further infrastructure upgrades may be required, and allowance has been provided in the model for site specific numbers to be included. Also note that the capital cost per head processed will reduce as the total annual number of head processed increases.

4.3.5.2 Maintenance and Service Costs

Maintenance and service costs are also supplied by the equipment manufacturer. Maintenance costs are additional running costs that the plant incurs with the installation of the equipment and include components such as parts and labour. The service contract covers ongoing service and maintenance of the system. The assumption is made that these costs will be a “per head cost” and for this reason no reduction in these costs is seen with increasing production.

4.3.5.3 Risk of Down Time

To estimate the cost of down time for an average installation 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 10 minutes. The same labour cost used for calculating increases in labour efficiency (Table 11) is used to calculate the cost of down time. The amount of weekly down time is an adjustable figure found on the “Costs” sheet of the model.

4.3.6 Summary Cost-Benefit Analysis

Benefits arise from improvements in operational efficiency, carcase yields and labour costs. However, at this time, carcase yields are the primary benefit to be analysed.

5. Conclusion

Offline results seen in Section 4.1 show a significant improvement in accuracy for both the rack analysis (4.1.1), loin analysis (4.1.2), and the product positioning (4.1.3). The accuracy results achieved offline represent the potential for a significant benefit to the customer when they are able to be integrated into a production system. Given that the majority of the benefits of the LEAP IV Middle system are due to accuracy these improvements will provide meaningful benefits to the customers once successfully implemented on site.

Due to software communications issues on site (see Section 4.2), the upgrade was unable to be tested on product at a processor's site. However, Scott is currently building a LEAP IV Middle system and the upgrade kit will be thoroughly tested during factory commissioning before it is deployed to an Australasian site. Once tested on site to ensure reliability the upgrade kit will be able to be easily retrofitted to existing LEAP IV installations, due to the lack of hardware changes.

5.1 Key findings

5.1.1 Offline accuracy improvements

The upgraded rack flap analysis was tested and compared to the existing analysis. As you can see in Table 12, the upgraded analysis has a median error of only 1.1mm, compared to 3.9mm for the existing analysis.

Table 12: Offline rack flap analysis results. Results are averaged across all cuts.

Rack Flap Analysis	Existing Analysis	Upgraded Analysis
Mean Error (mm)	4.1mm	1.3mm
Median Error (mm)	3.9mm	1.1mm
Standard Deviation (mm)	2.7mm	1.0mm
95th Percentile (mm)	8.2mm	3.3mm

The upgraded loin flap analysis was also tested on unseen images and compared to the existing analysis. Table 13 shows that the median error has decreased to just 2.1mm, compared to 5.5mm for the existing analysis.

Table 13: Offline loin flap analysis. Results are averaged across all cuts.

Loin Flap Analysis	Existing Analysis	Upgraded Analysis
Mean Error (mm)	6.8mm	2.5mm
Median Error (mm)	5.5mm	2.1mm
Standard Deviation (mm)	5.5mm	2.0mm
95th Percentile (mm)	17.0mm	6.3mm

5.1.2 Offline 3D positioning improvements

The existing loin analysis uses a product position that is calculated from x-ray data and then projected along the rails of the LEAP IV Middle system. A RGBD camera was tested successfully on site which had a depth accuracy of 2mm. However, in an effort to make the upgrade more easily retrofittable a software solution was achieved which, while not quite as accurate at 3.7mm, was significantly more accurate than the existing solution. Also, with the software solution the entire upgrade kit would be a software-only upgrade which allows for a simpler installation with less down time for any customer installations.

Table 14 shows the results for the new 3D positioning system compared to the existing positioning system. Note that due to the camera orientation as mostly aligned to the central axis of the LEAP IV Middle system the effect of a 1mm error in movement along the rail is significantly less that 1mm on the cut.

Table 14: Comparison of product position errors from x-ray derived position and AI technique derived position.

	X-ray Derived Position Error	**AI technique Derived Position Error**
Mean Error (mm)	30.1mm	4.4mm
Median Error (mm)	29.8mm	3.7mm
Standard Deviation (mm)	10.7mm	3.6mm
95th Percentile Error (mm)	46.6mm	11.4mm

5.1.3 Cost-Benefit Analysis

Greenleaf Enterprise Pty Ltd performed a cost-benefit analysis of the LEAP IV Middle system. The intention was to be able to compare the existing system (Mk 1) against the upgraded system (Mk 2). However, due to the communications issues encountered on site (see Section 4.2) the upgraded system was unable to be tested for the cost-benefit analysis. Accordingly, Greenleaf assumed the null hypothesis that both systems have the same performance.

5.2 Benefits to industry

The offline tests on the upgraded rack and loin flap analysis indicates an improvement by a factor of 2 – 3. There are additional benefits due to the reduced rework and ability to more accurately specify the cut positions. Once the factory and on-site commissioning of the upgrade kit are completed with the upcoming LEAP IV Middle system the Middle Upgrade kit will be able to provide significant benefits to both new LEAP IV systems, as well as existing systems as a retrofittable upgrade.

6. Future research and recommendations

Scott is currently continuing to develop the communications software to allow the upgraded analysis to robustly run in production. An upcoming LEAP IV Middle system is currently being built in the Scott Dunedin factory and once factory commissioning begins in August 2023 the software team will be able to thoroughly test the robustness of the upgraded software. Once this step is complete the upgrade kit will be available to upgrade existing LEAP IV installations and as standard for new LEAP IV systems in future.

Below are recommendations for future research, building on the learnings of this project:

- With the success of AI techniques in the analysis upgrades of this project and P.PSH.1302 a natural continuation of the development would be to investigate what accuracy improvements could be accomplished with AI techniques on the LEAP V Forequarter systems.
- The Scott Standalone Chine Machine currently produces superior yield results to the integrated chine station in the LEAP IV system, hypothetically, due to increased rigidity through the station. An engineering design review with the aim to equal the performance of the Scott Standalone Chine Machine would provide significant benefits to new LEAP IV installations, as well as existing installations.