Final report

P.PSH.1302 – LEAP III Sensing and Stabilisation Upgrade

Project code: P.PSH.1302

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Date published: 09 May 2024

PUBLISHED BY
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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.

1 Abstract

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

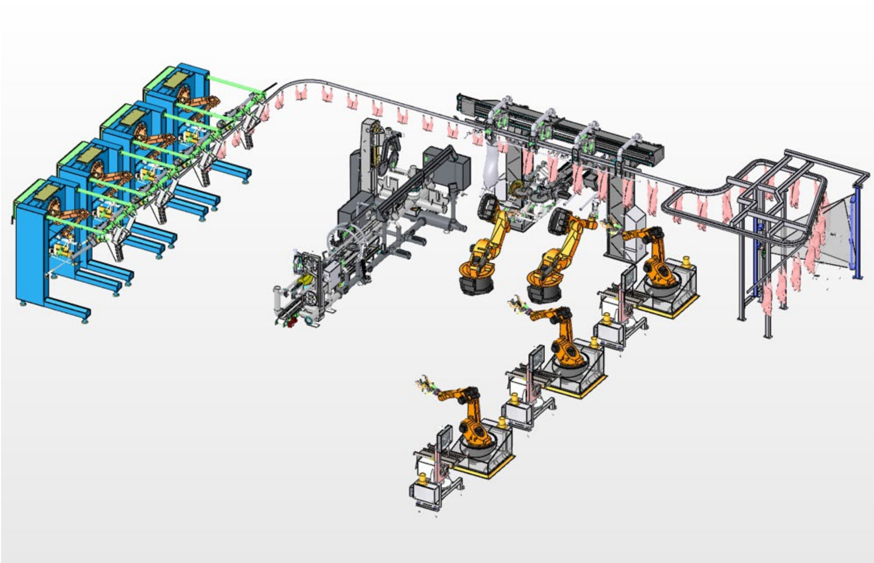

Figure 1: Boning Room Vision of a fully automated room.

There has been significant adoption and progress 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 to attain more benefit for the red meat value chain.

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 existing systems operating across Australia and New Zealand that there is substantial further benefit to be attained by upgrading the Dual Energy X-ray Absorptiometry (DEXA) and Primal systems to achieve the next level in accuracy and reliability. This project looks to build on this opportunity.

2 Executive Summary

Scott Technology Ltd and Meat and Livestock Australia (MLA) have created an upgrade kit for existing and future LEAP III Primal systems for automated lamb processing. The upgrades target improvements in design that increase the benefit from accuracy, achieve a reliable 10/minute throughput, as well as improving mechanical reliability (uptime efficiency).

The upgrade kit consists of three separate packages:

- A software upgrade to use dual-energy x-ray images, in combination with artificial intelligence (AI) techniques to improve the cut accuracy. This upgrade was independently tested at an Australian processor by Greenleaf Enterprises Pty Ltd and found to have a significant net benefit head over the current software and manual processing.
- A carcase stabilisation upgrade was designed, built, and deployed at sites in New Zealand and Australia. The carcase stabiliser was found to stabilise carcases more effectively through the x-ray scanning process, which is a key parameter in achieving accurate cuts. The new carcase scanning stabiliser was monitored closely at an Australian processor and after 400,000 carcases, showed no noticeable run-time swing.
- An automated lubrication system was designed, built, and deployed at sites in New Zealand and Australia. When first installed on site the new automated lubrication system was closely monitored for 6 months of production and was found to have a significantly improved and more consistent delivery of oil to the bearings. Additionally, the indicator lights on the automated lubrication system provides a clear and obvious indicator to maintenance staff when a lubrication cannister required replacing.

The three upgrade packages are all able to be retrofitted to existing machines or included in future machines. With the upgrades successfully installed and demonstrated on Australian sites the objectives of the P.PSH.1302 project have been achieved and an upgrade kit is now available to provide benefit to the Australasian lamb processing sector.

2.1 Summary results – Cost benefit analysis

The current install has been operating for a number of years and the net benefit over manual cutting of the current install or upgraded software are listed:

1. The current software install, using data collected at the Australian install demonstrated between $0.26 and $0.50 /head net benefit.
2. The upgraded software install, using data collected at the Australian install demonstrated between $0.31 and $0.67 /head net benefit.

The variation in financial benefit for each analysis is due to measurement accuracy by the system and technology utilisation by the plant.

The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has improved the forequarter-rack (FQ) cutting line due to:

a. Consistent number of ribs in the FQ. Additional 12% of FQs cut to the 4^{th} rib
b. Accuracy of mm of meat left on the caudal end of the last FQ rib, resulting from an improvement in the pitch of the cutting trajectory of the robotic saws.

The upgraded primal machine's payback period is between 1.63 and 2.94 years. The outcome from these upgrades is an increase accuracy of the forequarter-rack cutting line. Table 1 summarises the investment and likely payback for the system.

Table 1: Summary of benefits for Brooklyn install, current vs. upgraded software, relative to manual cutting performance

SUMMARY PERFORMANCE MEASURES				
	Current Software		Upgraded Software	
Hd / annum	2,122,038		2,122,038	
Production increase with equipment	3.13%		3.13%	
	From	To	From	To
Capital cost (pmt option, upfront)	$2,775,418		$2,775,418	
Gross return Per head	$0.41	$0.65	$0.46	$0.82
Total costs Per head	$0.15		$0.15	
Net Benefit Per head	$0.26	$0.50	$0.31	$0.67
Annual Net Benefit for the plant	$554,553	$1,068,436	$665,290	$1,430,219
Annual Net Benefit for the ex cap	$832,095	$1,345,978	$942,832	$1,707,761
Pay back (years)	3.34	2.06	2.94	1.63
Net Present Value of investment	$2,936,569	$6,308,334	$3,663,153	$8,682,121

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1 Background

1.1 Milestone 1

Milestone 1 was structured to develop an upgrade kit for the Scott/MLA LEAP x-ray Primal system to improve accuracy and reliability.

The Milestone was intended to culminate in a detailed concept plus a set of designs that are able to be released for manufactured in Milestone 2.

1.2 Milestone 2

Milestone 2 was structured to build and demonstrate the upgrade kit for the Scott/MLA LEAP x-ray Primal system to improve accuracy and reliability.

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 x-ray analysis, materials handling, and automated lubrication of the x-ray and Primal machine to achieve an uplift in accuracy and reliability.

Specifically, this Milestone is targeting an upgrade kit to provide the following improvements:

1) Increase cut accuracy of the LEAP system through development of software analysis to incorporate the additional information attained from DEXA and leverage machine learning and Artificial Intelligence (AI) techniques for image analysis.
2) Increase cut accuracy, reliability, and uptime by upgrading the materials handling in the x-ray system.
3) Increase machine performance and reliability by making improvements to the system lubrication system to get reliable consistent automated lubrication.

This Milestone culminated with the build, implementation, and demonstration of kit components which was evaluated in the following Milestone. These upgrades will enable Greenleaf Enterprises to assess the benefit of the upgrade kit in Milestone 3.

1.3 Milestone 3

Milestone 3 was structured to measure the benefits of the upgrade kit for the Scott/MLA LEAP x-ray Primal system. In the Milestone Greenleaf Enterprises Pty Ltd will update the LEAP Cost-Benefit Analysis model following the installation of the upgrade kit, developed in the previous Milestone.

This Milestone culminated in a report being submitted which summarised the value benefit and main drivers for the adoption of the upgrade kit for Australian lamb processing plants.

1.4 Milestone 4

Milestone 4 was structured to summarise the P.PSH.1302 project including a description of the aspects of the upgrade kit, and their performance. This Milestone culminated in the Final Report of the project.

2 Objectives

2.1 Project objectives

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 final report details the upgrade packages that have been developed and deployed.

The upgrades targeted improvements in design aimed at increasing the benefit from accuracy and mechanical reliability.

As a result of this project Scott and MLA have a set of upgrades that can be rolled out as retrofittable packages to any existing machines as well as incorporated as standard into new machines. This presents an opportunity for greater Return on Investment (ROI) for these machines and for the industry more broadly.

3 Methodology

The upgrade kit consists of three packages, which are intended to improve the LEAP III Primal through an increase in accuracy, a reliable 10/min throughput, and improved mechanical reliability.

The three packages of the upgrade kit are an upgrade to the vision analysis (Vision analysis upgrade 3.1), an upgrade to the carcase scanning stabiliser (3.2), and an upgrade to the lubrication of LEAP III Primal (3.3).

3.1 Vision analysis upgrade

Skeletal identification can be further improved by utilising the material differentiating properties of dual-energy x-rays, combined with the use of artificial intelligence (AI) techniques including machine learning. These techniques have been rapidly improving in industry and have made significant improvements in recent work completed in LEAP 4 Beef and initial lamb investigations. This project developed the improved skeletal identification software as well as upgrade the network communications software to achieve known reliability improvements. Figure 2.

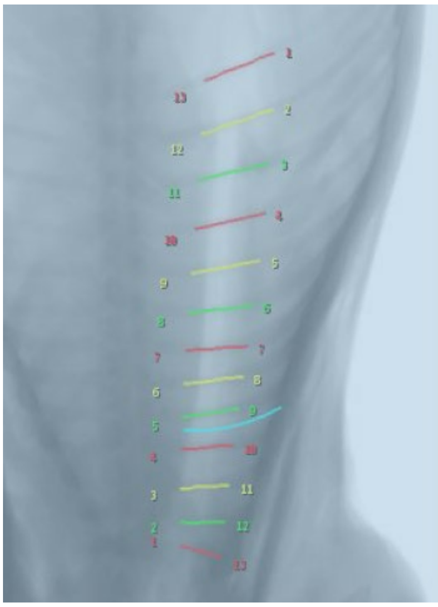

Figure 2: Lamb carcase rib tracing algorithm currently utilises single energy information.

3.2 Carcase stabilisation upgrade

The carcase stabiliser (Figure 3) is critical to achieving a stable carcase and hence consistent x-ray images. This in turn underpins the determination of accurate cutting lines and Objective Carcase Measurement (OCM) data. It is proposed to review the design to seek greater stability and reliability across the range of carcass sizes. This project developed an improved carcase stabiliser which will improve cut accuracy and reliability for the LEAP III Primal systems.

Figure 3: Accurate automated processing requires consistent and controlled carcases.

3.3 Automated lubrication system upgrade

The lubrication system is used throughout the LEAP system and is integral to ensuring reliability and longevity of machine components. Due to the highly variable operating environment and resulting effect on viscosity conventional pressurised lubrication systems are not able to reliably apply lubrication. In a processing plant application lubrication is critical for moving carriages on precision linear bearings and to help prevent corrosion from the aggressive cleaning chemicals which are used in industry. Loss of lubrication typically results in highly costly failures and downtime. On feedback from industry partners and assessing historical records indicatively:

- Premature failure of lubrication cartridges can cost system owners a substantial amount to replace them.
- There is significant labor savings from having a reliable lubrication system as this allows maintenance to attend to other requirements while the Scott lamb Primal system continues in production.

Until recently Scott had been using a SKF LAGD gas charge system filled with grease on the LEAP Primal and Middle systems in production however, there were several modes of failure:

- Failure to fully discharge which shortens the service life.
- Line blockages: grease blockages due to low temperature application.
- Leakage past the drive piston.
- Lube Cartridge breakage due movement of servo driven carriages.
- Oil back flowing from Linear Bearing
- Not enough Lubrication pressure in lines.

Figure 4: Consistent and reliable lubrication is critical to machine performance, reliability, and ultimately cost of ownership.

This project developed a new dosing system which will have far reaching benefits within the LEAP system and potentially other plant equipment (Figure 4).

4 Results

4.1 Vision analysis results

The most common failure mode of the current analysis is incorrect rib numbering, e.g., missing the first rib and then labelling the second rib as rib number one. The vision analysis upgrade package sought to improve the rib numbering of the current analysis. Two different approaches to the rib numbering problem were tried and the more successful approach was then installed at an Australian processing site and independently audited by Greenleaf Enterprises Pty Ltd (Greenleaf).

4.1.1 Testing with product at a partner processor – Only images checked

After the AI was trained and tested offline the next step was to test the AI in production at an Australian processor. This test involved running alternate batches of product with either the current analysis or the AI analysis. This ensured that the products seen by both analyses are similar in nature and also serve as a test that the AI analysis can be used successfully in production and check for issues of timing and processing power in a production environment.

An ideal test would involve evaluating the relative performances of the analyses by running each analysis and physically counting the resulting forequarter cuts for each product. However, in the large majority of carcases the analyses will agree and provide the same rib numbering and cut accuracy. Therefore, to accurately compare the relative performances a large sample size is required. As a penultimate test the decision was made to perform the test on the images rather than manually checking product. This would allow a large enough sample size with the resources available for this test. For the tests in the next subsection the cut accuracy was determined with product measurements but for this test the accuracy was taken from the images. During the test, product was periodically checked to ensure that cut accuracy was acceptable however, this was only done for short periods rather than continuously through all 6240 carcases.

During the test the AI analysis ran smoothly and there were no issues with timing or processor power. Additionally, it was a matter of a few seconds to change over from the AI analysis to the current analysis which helped from an operational point of view.

For both analyses multiple trials were run and then the images were manually marked to determine if the analysis was correct. The results of the trials are shown in the tables below.

4.1.2 Current Analysis Results

Table 2: Current analysis results from testing on site.

Trial Number	Incorrectly Analysed	Total	
1	36	1180	
2	40	600	
3	32	400	
4	22	580	
Combined	**130**	**2760**	

4.1.2.1 Upgraded Analysis Results

Table 3: AI analysis results from testing on site.

Trial Number	Incorrectly Analysed	Total	
1	22	960	
2	3	390	
3	7	580	
4	18	390	
5	14	670	
6	14	490	
Combined	**78**	**3480**	

4.2 Rib Detection Accuracy Independent Validation

As part of this project Greenleaf Enterprises Pty Ltd (Greenleaf) conducted an independent cost-benefit analysis of the accuracy improvements from the upgraded analysis. Their summary findings are given below:

To establish the dollar value of each of the listed costs and benefits as a per head number, the below production numbers were used for the annual benefit calculations (Table 3). The table summarises Manual, Current, and Upgraded throughputs, noting there has been no throughput increase assigned to the Ex-post analysis to date. It should be noted, accurate annual volume processed will vary depending on seasonal supply. Thus, these throughputs have been used as a baseline for the analysis and the financial benefit increases with number of lambs processed.

Table 4: Calculation used for determining production volume base line.

Processing room operation speeds		
	Current Software	**Upgraded Software**
Carcases / min	10.00	10.00
Carcases / Statn./hr	600	600
Carcases / day	10800	10800
Annual days	196	196
Annual # of hd	**2,122,038**	**2,122,038**

Installation of an automated cutting system has shown in previous studies to have an immediate increase in productivity; the estimated increase in room throughput used for the ex-ante report was 6% without increasing the number of labour units[1]. However, this has been excluded from this review.

The sales prices used in the cost-benefit analysis are given in Table 4. All results are based on 2023 cut prices, to compare between manual and automated results, as price changes are caused by market fluctuations, not the system.

[1] This increase in productivity resulted in a greater volume of carcases processed per day. Livestock lairage, slaughter capacity, carcase chilling capacity, boning room capacity and finished product chilling and storage capacity all place different constraints on a plants overall daily production capacity. Every plant has a different combination of these constraints, most of which are dependent on the mix of livestock types, cutting specifications and market destinations. However, in most cases plants do not operate at maximum capacity and the productivity gains mentioned here will be realisable.

Table 5: Retail Sales values used for driving economic analysis

Average discount level		20%
Cut	$/kg	Discount Value
Whole Carcass	$ 7.50	$6.00
Rack	$ 26.51	$21.21
Rack (Discount)	$ 21.21	$16.97
65CL Trim	$ 6.28	$5.02
75CL Trim	$ 6.28	$5.02
Shoulder	$ 10.65	$8.52
Shoulder Rack	$ 27.10	$21.68
Shortloin	$ 27.10	$21.68
Render	$ 0.16	$0.13
Tenderloin	$ 25.34	$20.27

The accuracy of the forequarter cut is given below in Figure 5 and Figure 6, where Figure 5 shows the number of ribs in the processed forequarter (with the machine selected to produce 4 rib forequarters). Figure 6 then looks at the millimetre accuracy on each cut, i.e., how closely aligned the cuts are to the final forequarter rib.

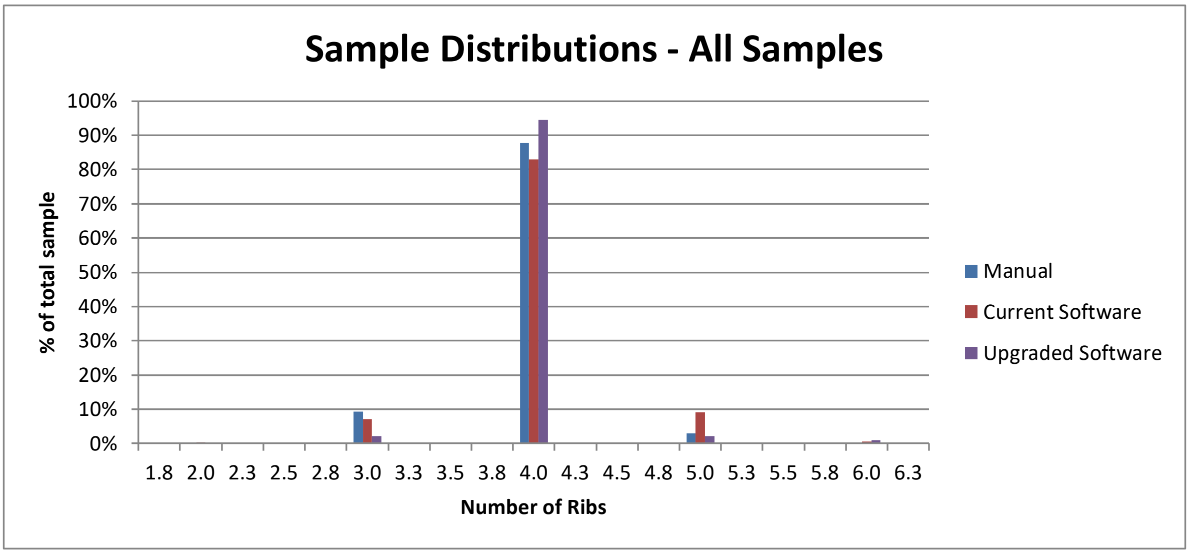

Figure 5: Shoulder cut accuracy observations for both manual and x-ray cutting systems

The additional 12 % of FQs cut to a 4th rib specification in Figure 5 were a focus of the Upgraded Software. By reducing the number of 5th rib FQs, more meat is cut onto the rack and loin piece, increasing value extracted from the carcase.

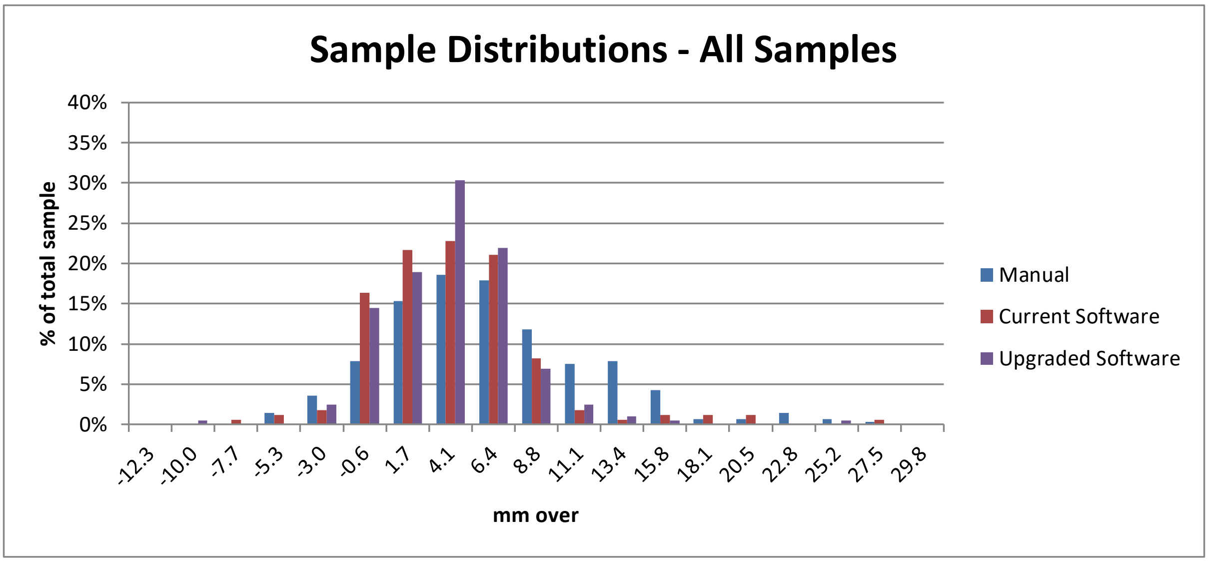

Figure 6: Distance of cutting lines from the edge of the 4th rib on a 4-rib shoulder cut.

The distance in millimetres that the shoulder cut was made above or below the final FQ rib is summarised in Figure 6 for each cutting method observed. Negative values show where the cutting line has cut into the caudal edge of the final FQ rib. Positive values show where the cutting line is located closer towards the cranial edge of the first rack and loin rib, thus taking more loin from the rack and leaving it on the shoulder. The main point to note from the Figure 6 is the variation in distance away from the edge of rib was minimal, with the Upgrade Software results showing a tighter distribution around the 4 mm mark. In fact, 99% of Upgraded Software cuts were conducted at no more than three millimetres into the final FQ rib, and no more than 11 millimetres off the edge of the final FQ rib. The benefits observed are informed by data collected on-site in Australia by Greenleaf between 2017 and 2023.

The methodologies used to analyse and present the data were maintained from previous reports. The detail summarised reflects the range in values observed in the data collected. These results demonstrate the financial performance of the machine for current or upgraded software scenarios, relative to manual operations.

The variation in financial benefit for each analysis is due to measurement accuracy by the system and technology utilisation by the plant.

The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has improved the forequarter-rack (FQ) cutting line resulting in:

a. Consistent number of ribs in the FQ.
b. Accuracy of mm of meat left on the caudal end of the last FQ rib.

Realistically, installation refinements and system improvements facilitated by the manufacturer to reduce cutting variation and increase value from improved cutting accuracy vary from site to site. Additionally, some variation will be caused by plant-specific drivers, like number of head processed per day.

The benefits identified are broadly summarised as either product value or process efficiency benefits. The larger portion of benefits is related to product value. The graph will change as labour market and throughput supply fluctuate, impacting process efficiency benefits.

Scott's automated equipment improves cutting line accuracy and increases carcase retail value. The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has focused on the forequarter-loin (FQ) cutting line, improving the consistency with which the machine cuts the number of ribs in the FQ.

Automated cutting technology delivers a technical cutting advantage over manual systems per product specification, yield gains per bandsaw dust reduction, and increased shelf life. Benefits relating to process improvements were not factored in, such as increased labour productivity through more consistent product flows, and a reduction in labour units required. OH&S costs have also reduced with safety risk.

4.3 Summary Results - Cost Benefit Analysis

The results reported in this section are based on the model drivers summarised in 4.2.1. The benefits observed are informed by data collected on-site in Australia by Greenleaf between 2017 and 2023.

The methodologies used to analyse and present the data were maintained from previous reports. The detail summarised in Table 11 of the current report reflects the range in values observed in the data collected. These results demonstrate the financial performance of the machine for current or upgraded software scenarios, relative to manual operations.

Variance observed across the sample data reflects a range in values expected and is reported using the upper and lower 95% confidence intervals in Table 12 as "From" and "To" values for each scenario.

This study estimates a net benefit for -

1. The current software install, using data collected at the Australian install demonstrated between $0.26 and $0.50 /head net benefit
2. The upgraded software install, using data collected at the Australian install demonstrated between $0.31 and $0.67 /head net benefit

Delivering an estimated time to payback between 2.06 to 3.34 years, and 1.63 to 2.94 years. The outcome from these upgrades is an increase accuracy of the forequarter-rack cutting line.

The variation in financial benefit for each analysis is due to measurement accuracy by the system and technology utilisation by the plant.

2. The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has improved the forequarter-rack (FQ) cutting line
    a. Consistent number of ribs in the FQ. Additional 12% of FQs cut to the 4th rib
    b. Accuracy of mm of meat left on the caudal end of the last FQ rib

Realistically, installation refinements and system improvements facilitated by the manufacturer (to reduce cutting variation and increase value from improved cutting accuracy) vary from site to site. Additionally, some variation will be caused by plant-specific drivers, like number of head processed per day.

Table 6: Summary of benefits relative to manual cutting performance.

SUMMARY PERFORMANCE MEASURES				
	Current Software		Upgraded Software	
Hd / annum	2,122,038		2,122,038	
Production increase with equipment	3.13%		3.13%	
	From	To	From	To
Capital cost (pmt option, upfront)	$2,775,418		$2,775,418	
Gross return Per head	$0.41	$0.65	$0.46	$0.82
Total costs Per head	$0.15		$0.15	
Net Benefit Per head	$0.26	$0.50	$0.31	$0.67
Annual Net Benefit for the plant	$554,553	$1,068,436	$665,290	$1,430,219
Annual Net Benefit for the ex cap	$832,095	$1,345,978	$942,832	$1,707,761
Pay back (years)	3.34	2.06	2.94	1.63
Net Present Value of investment	$2,936,569	$6,308,334	$3,663,153	$8,682,121

The benefits identified are broadly summarised as either product value or process efficiency benefits. The larger portion of benefits is related to product value, as in Figure 32. The graph will change as labour market and throughput supply fluctuate, impacting process efficiency benefits.

Scott's automated equipment improves cutting line accuracy and increases carcase retail value. The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has focused on the forequarter-loin (FQ) cutting line, improving the consistency with which the machine cuts the number of ribs in the FQ. Automated cutting technology delivers a technical cutting advantage over manual systems per product specification, yield gains per bandsaw dust reduction, and increased shelf life. Benefits relating to process improvements were not factored in, such as increased labour productivity through more consistent product flows, and a reduction in labour units required. OH&S costs have also reduced with safety risk.

The contribution of each benefit and its dollar value is summarised in Figure 33.

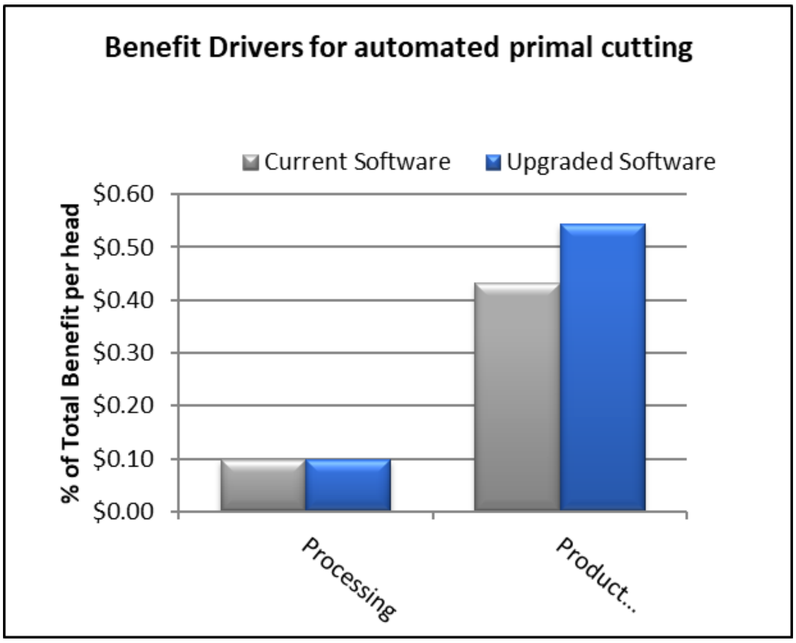

Figure 7: Broad grouping of benefits delivered by Scott's x-ray primal cutting solution

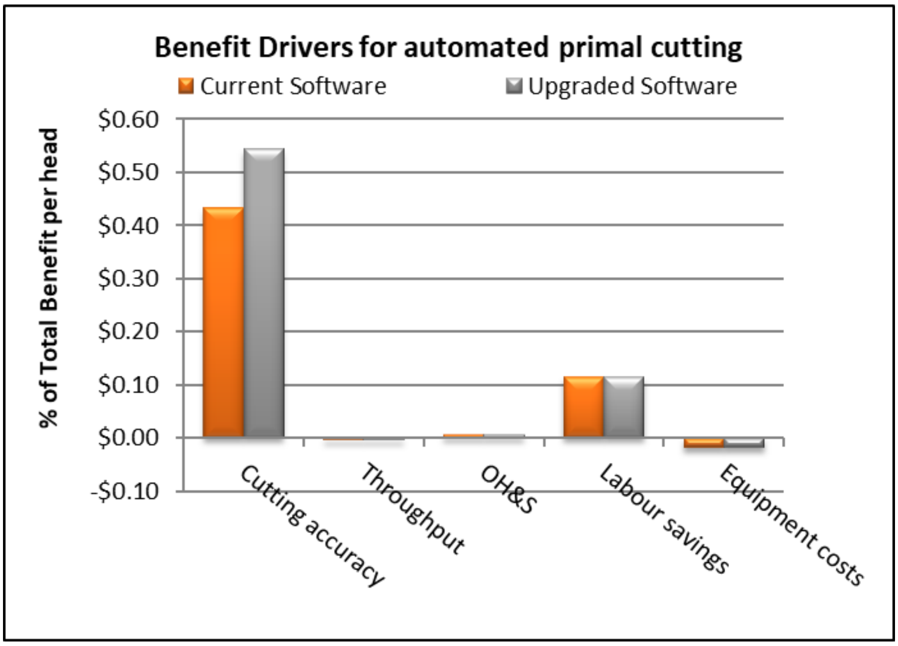

Figure 8: Summary of benefits delivered from Scott's x-ray primal cutting solution

4.3.1 Calculating value of benefit

Performance targets for manual and automated systems are driven by product cut specifications, operational targets and customer willingness to pay. A mix of high and low performance (i.e. accuracy) processes can be optimised across financial, product, process and market variables to maximise value to the plant. The 2023 primal cutting system is compared back to 2017 manual operations. These systems need to be equalised to understand the optimum value available.

Table 12 summarises benefit relative to manual processes, per process. The upgraded scenario benefit for this plant is between $0.46/hd and $0.82/hd.

Table 7: Summary of individual benefits associated with automated x-ray primal cutting

TOTAL BENEFIT					
		Current Software		Upgraded Software	
Benefit Summary		$/hd From	$/hd To	$/hd From	$/hd To
1.1 Accuracy Benefit	Cut 1 (FQ-Mid)	$0.16	$0.21	$0.21	$0.38
	Cut 2 (Rack SLP Split)	$0.00	$0.00	$0.00	$0.00
	Cut 3 (HQ-Mid)	$0.15	$0.35	$0.15	$0.35
2. Throughput Benefit		$0.00	$0.00	$0.00	$0.00
3. OH&S Benefit		$0.01	$0.01	$0.01	$0.01
4. Labour Benefit		$0.11	$0.11	$0.11	$0.11
Equipment costs	**Maintenance**	$0.00	$0.00	$0.00	$0.00
	Operation	$0.00	-$0.01	$0.00	-$0.01
	Risk of failure	-$0.01	-$0.01	-$0.01	-$0.01
	$ Benefit per head	**$0.41**	**$0.65**	**$0.46**	**$0.82**
$ Annual Benefit overall plant		**$870,551**	**$1,384,434**	**$981,288**	**$1,746,217**

These figures demonstrate the total costs involved and highlight areas where future savings could be generated.

Figure 34 shows the difference in cost between the systems. Thickness of the box in the graph represents the upper and lower variation in expected value based on performance variation captured in the data.

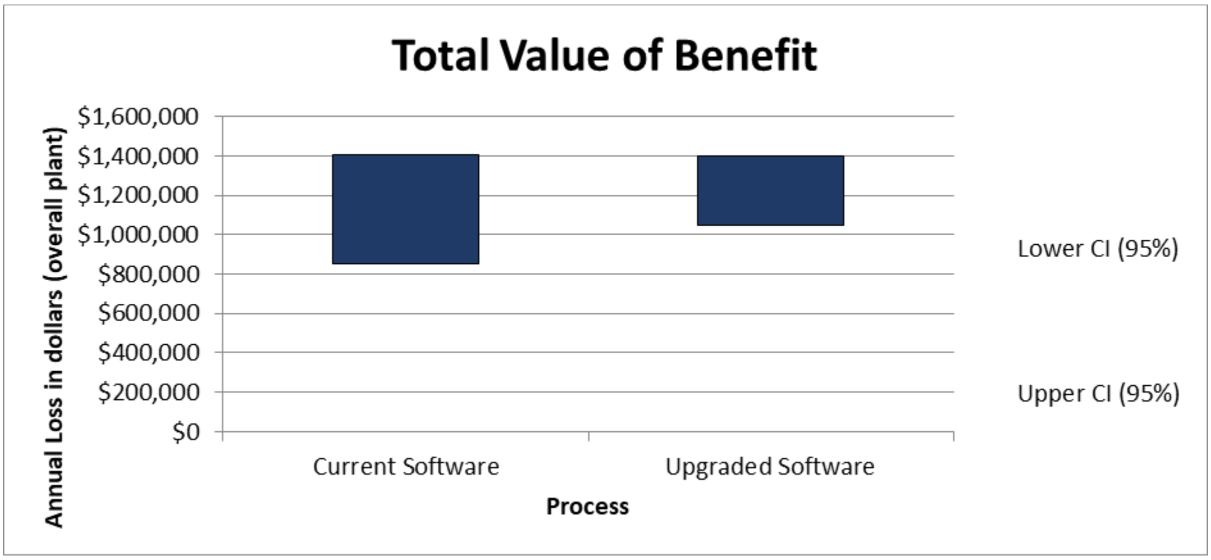

Figure 9: Improvement in benefits over manual operation from Table 13

A more detailed breakdown of the costs and benefits are included in Table 14 and Table 15.

4.3.2 Breakdown of costs and benefits

Table 8: Summary of forecast and actual benefits for the primal cutting system

	Current Software	Upgraded Software
Hd / annum	2,122,038	2,122,038
Production increase with equipment	3.13%	3.13%

SUMMARY PERFORMANCE MEASURES				
	Current Software		Upgraded Software	
Benefit summary	$/hd		$/hd	
	From	To	From	To
$ Accuracy Benefit per head	$0.31	$0.56	$0.36	$0.73
$ Technique Benefit per head	$0.00	$0.00	$0.00	$0.00
$ Labour Benefit per head	$0.12	$0.12	$0.12	$0.12
$ Automation Costs	($0.01)	($0.02)	($0.01)	($0.02)
$ Overall Benefit per head	**$0.41**	**$0.65**	**$0.46**	**$0.82**

COST ASSOCIATED WITH THE EQUIPMENT		
	$/hd	$/hd
Capital cost	$0.13	$0.13
Maintenance	$0.00	$0.00
Operation	$0.01	$0.01
Risk of mechanical failure	$0.01	$0.01
Total cost per head	$0.15	$0.15
Total cost per head (EX CAP)	$0.02	$0.02

Table 9: Costs and benefits breakdown for the primal cutting system installation at 5.2 hd/minute

Benefit Drivers for automated primal cutting				
	Current Software		**Upgraded Software**	
	$/ hd	$/ annum	$/ hd	$/ annum
Processing	$0.10	$209,562	$0.10	$209,562
Product value	$0.43	$917,930	$0.54	$1,154,190
	$0.53	**$1,127,492**	**$0.64**	**$1,363,753**
Cutting accuracy	$0.43	$917,930	$0.54	$1,154,190
Throughput	$0.00	-$7,272	$0.00	-$7,272
OH&S	$0.01	$13,623	$0.01	$13,623
Labour savings	$0.11	$241,667	$0.11	$241,667
Equipment costs	-$0.02	-$38,456	-$0.02	-$38,456
	$0.53	**$1,127,492**	**$0.64**	**$1,363,753**

4.3.3 Financial viability of equipment

Based on the drivers shown in Table 14 the following analysis provides a net annual return of $1,363,753 (exclusive of capital costs). Considering an initial total cost of investment of $2,775,418 this delivers a payback period between 1.63 and 2.94 years at current processing rates. A 10-year operation of the investment and discount rate of 8.5% (and all other factors being equal) estimates NPV between $3,663,153 and $8,682,121.

4.4 Carcase stabilisation results

The upgrades to the carcase stabilisation were built and installed into a production environment as part of one system installed and operational on the 13th of December 2021 and another system that has been operational since December 2022. Since this time and up until the time of writing this report, the carcase stabilisation upgrade has handled more than 1.3 million carcases between these two sites.

Given the natural variation and pliability of chilled lamb carcases as well as the requirement to achieve a 10 carcases per minute throughput rate, x-ray scanning is performed on a continuous chain so that carcases are not required to come to a stop, return to a natural hung shape and remain stationary for sufficient time to acquire images. This significantly reduces the footprint and complexity of the x-ray scanning arrangement and presents carcases in a state closest to that achieved when cutting which optimises the transportability of the scan data relative to the true form of the carcase.

Stabilisation of the carcase during vision scanning is imperative for achieving accuracy as the carcase must present to the scanner in the same orientation and stature as when the cutting is performed. A specially designed carcase stabilisation infeed and control mechanism is implemented in the region where the scan is completed to ensure carcases are aligned to a plane co-incident with the rail and hung naturally and in a non-deformed state below the rail. This hardware is designated the 132 Stabiliser assembly.

This project has made significant upgrades to the stabiliser assembly to leverage learnings from installed systems having run significant quantity and variety of carcase products. Upgrades target the known variation in hock location relative to the rail, carcase size variation, inconsistencies experienced with hung carcase pre-processing and condition as well as the variation measured in hook and gambrel shapes and sizes.

It is known from experience that when these variations exceed certain limits that carcases will not be stabilised adequately and will pivot about the gambrel (hanging point) by an instance or a combination of the following:

a) Swinging back and forth toward and away from the x-ray source causing the depth perception of skeletal features to be mis-interpreted with respect to their true position relative to the rail.
b) Swinging side to side perpendicular to the fan beam created by the x-ray source and defined in 2 dimensions by the x-ray detector causing the skeletal image to be stretched and compressed in regions leading to incorrect interpretation of skeletal feature locations relative to the centre of the carcase.
c) Bouncing up and down to and away from the rail which causes the depth and vertical representation of skeletal features to be mis-interpreted with respect to their true position relative to the rail and the centreline of travel.

The following upgrades, Figure 7 and Figure 8, were developed in Milestone 1 and built and installed in Milestone 2.

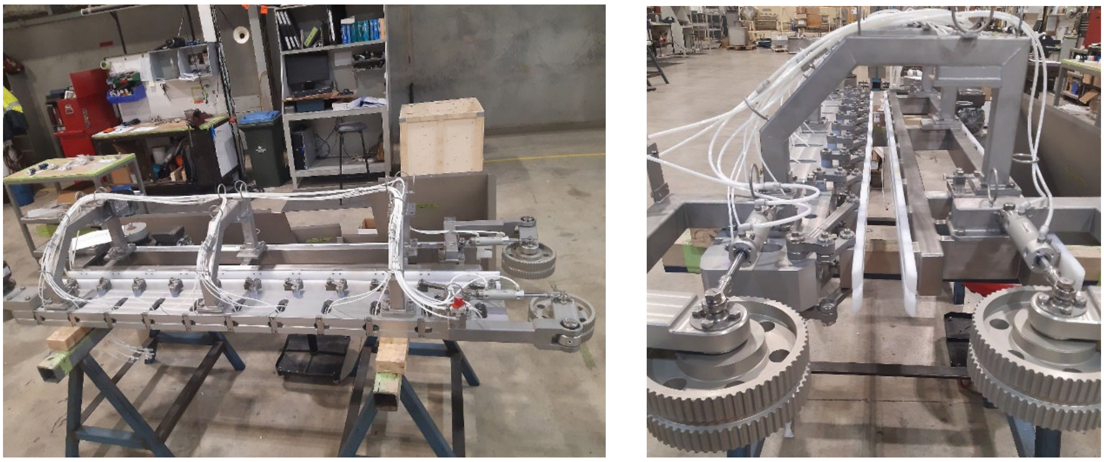

Figure 10: Stabilisation upgrade is a standalone assembly that can be retrofitted to existing as well as built for new systems.

As an assembly the upgrade is self-contained and controlled so that it can be applied and tuned to any existing or future x-ray installation without substantial integration changes. The length of the stabiliser is designed to capture the carcase prior to entering the x-ray scan beam and maintaining control of the carcase to a point where the carcase has completely passed through the x-ray beam and an image has been acquired.

Pneumatic design is de-centralised so that the on-board circuit is able to perform all the required functions without centralised valve control or actuation.

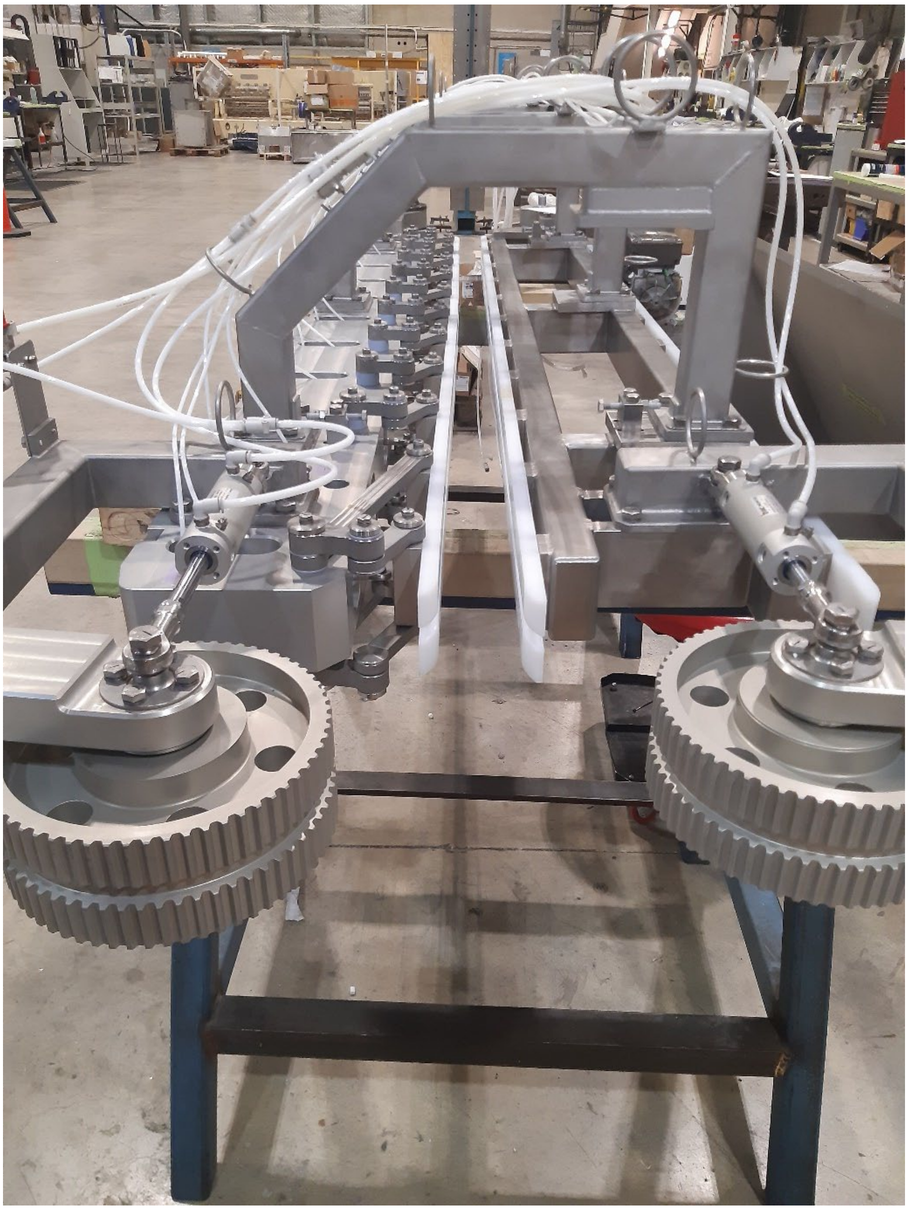

Figure 11: Stabilisation upgrade working principals to accommodate variations in product, process, and gambrel hardware.

To account for the significant variation in lamb carcase hock sizes and upstream processing variations the stabiliser is designed with one fixed rail (on the right-hand side of the image above), which establishes the reference location that can be translated to the downstream cut locations and one loaded floating rail (left hand side of above image) which applies a consistent and tuneable retraining (clamping) force to the hocks.

The clamping is applied with a series of pneumatically sprung linkages as shown in Figure 8. As product passes through the stabiliser assembly the floating rail yields to accommodate the width of hock and gambrel for every carcase while applying a consistent and even pressure to hold the hocks against the fixed rail.

Two belts (removed in the above image for clarity) are driven in synchronisation with the carcase imaging chain to keep the hocks constrained relative to the rail while the carcase moves through the system. The belt tension is kept consistent with a pre-loaded tensioning system shown on the sprockets in the foreground of Figure 8.

The aim was to maintain a plumb line (Figure 9) from the skid gambrel hock to the front of the spine at position close to the forequarter fourth rib cut position. Figure 10 shows neck twist. Figure 11 shows trials.

Figure 12: Laser line for carcase swing

Figure 13: View of lamb neck showing twist.

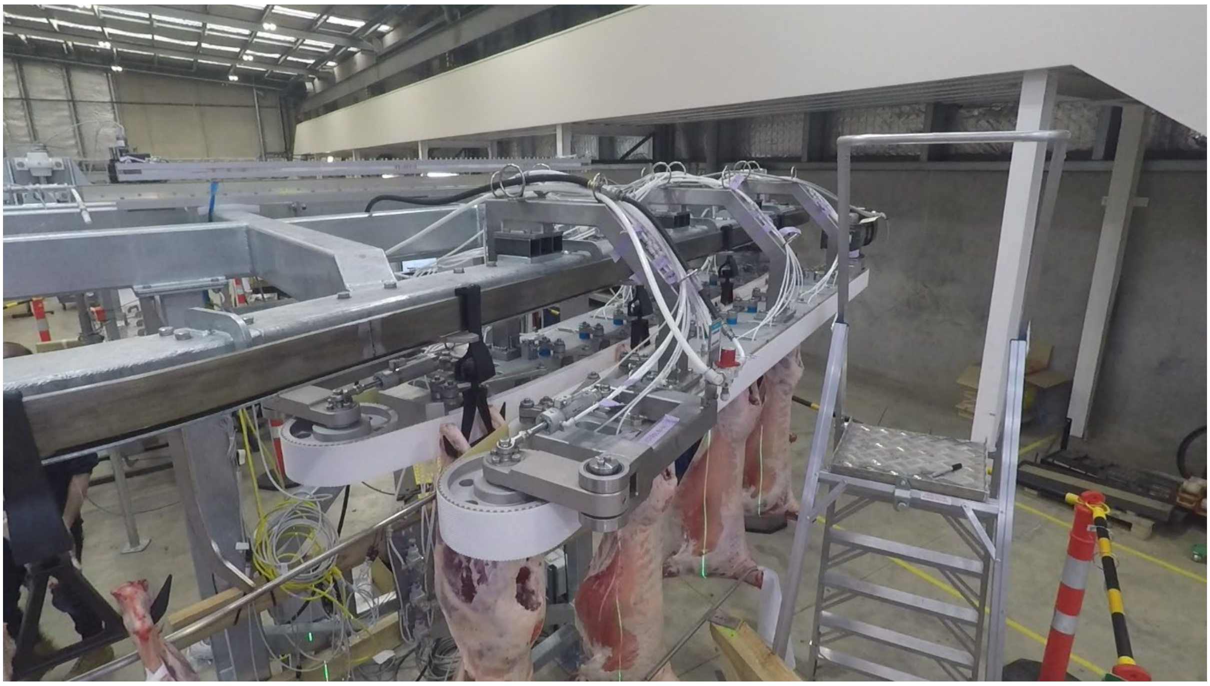

Figure 14: Overall view of carcases entering stabiliser during offline trials.

Stabiliser carcase swing testing

A smartphone accelerometer using the 'Science Journal' application was installed and setup to measure the moving carcase as it passed through the stabiliser: this allows the accelerometer data to be accessed and recorded. The app was set up to record acceleration in the X, Y, Z directions, linear acceleration, and compass angles. The phone was mounted inside a carcase, which was then sent through the stabiliser experimental setup. As part of the testing, swing was induced artificially by applying forces in the direction of each known failure mode. This enabled a worst-case carcase instability to be modelled to assess the stabiliser's ability to arrest the unwanted movement.

On Figure 12, Figure 13 and Figure 14 the blue lines represent the acceleration data collected. The black lines show when the carcase transitioned from one section of the experimental apparatus to the next and the areas either side of the stabiliser can be discarded from the analysis. Note that this is not relevant to the final data but used in interpretation. The red box highlights the area where the carcase was in the stabiliser. Note that every dataset shows a peak in linear acceleration as the carcase enters the stabiliser and as it exits. The peak before entry is induced for testing purposes, to highlight how rapidly the stabiliser can limit movement.

Throughout all the results, the linear acceleration when the carcase is in the stabiliser is limited to under $0.1m^2s^{-1}$. It is also clear that when swing is induced, the stabiliser reduces this rapidly.

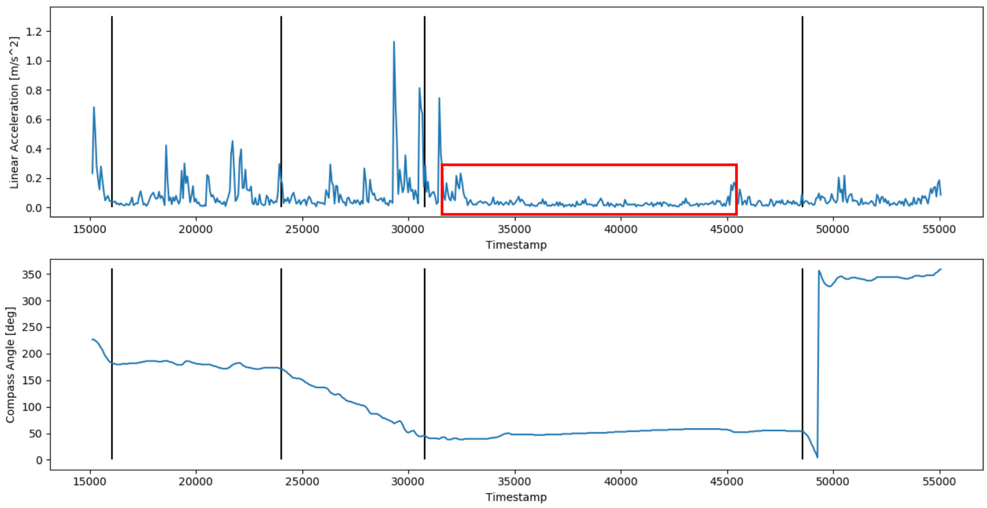

Figure 15 Carcase pushed in the direction of movement immediately after being put on the rail.

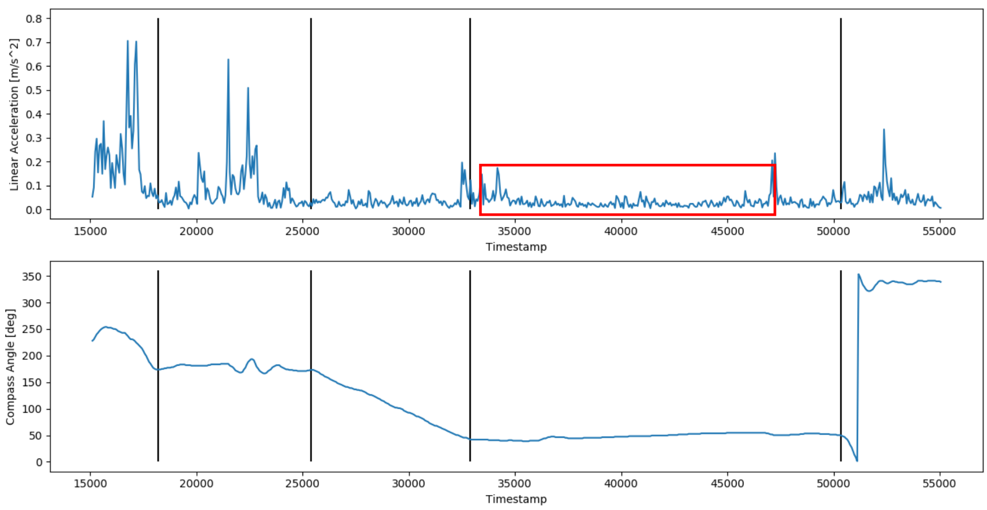

Figure 16 Carcase pushed in the direction of movement immediately after being put on the rail.

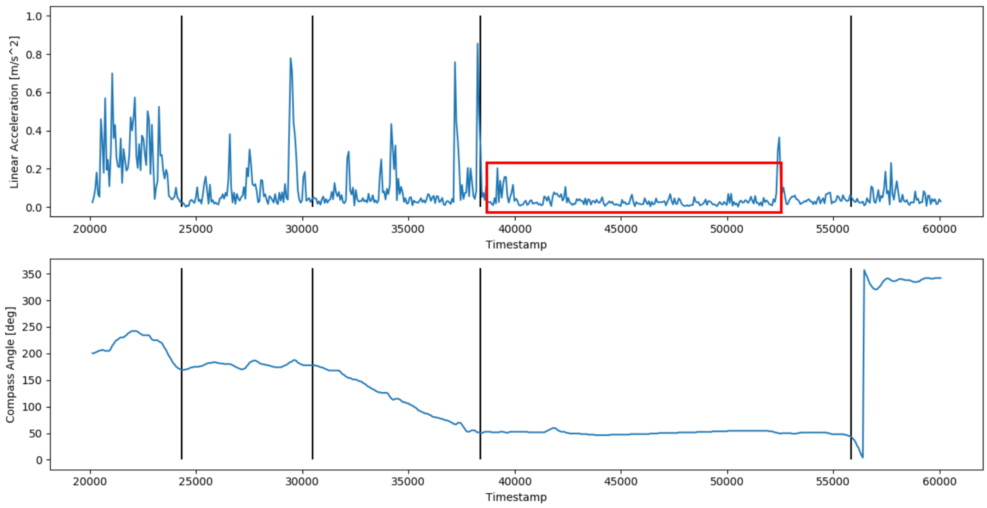

Figure 17 Carcase pushed in the direction of movement immediately after being put on the rail.

4.5 Automated lubrication system results

The lubrication upgrade has been designed, built, and installed at two sites, one in Australia, and one in New Zealand. It was closely monitored during the commissioning phase wherein it performed over 201,000 cycles under production conditions before it was deemed a successful installation.

Scott have investigated the issues associated with in-service failures of LEAP lubrication systems and evaluated the main environmental conditions the systems encounter.

- High pressure Hot/Cold water jet cleaning
- Chemical resistance
- Temperature variances/fluctuations (+60°C to 3°C)
- Back pressure (suction) from bearing block high velocity motion.

The current system supplied with the Scott equipment is a “Gas Discharge” type of single point lubricator. This lubricator has been found to have the following issues in service in the above environmental conditions:

- Piston stops moving or discharging the grease – Due to either the gas discharge cell emptied without pushing all the grease out, or the gas discharge cell is no longer operating. The cause of these failures was determined to be due to temperature fluctuations affecting the gas cell, or the life period of the gas discharge cell was exceeded.
- Air locks in the delivery line to the bearing grease point, and air locks in the canister. The cause of these failures was due to the high velocity movement of the bearing causing suction and back pressure on the delivery line back to the canister.
- The lubrication canisters were not noticed as empty by maintenance staff and subsequently the bearing was not lubricated for periods. The cause of this failure is due to the lack of visibility of the canister contents from the floor.

- Lack of lubrication on any linear bearing significantly reduces the life of the bearing and rail especially with the chemical washdown environment. A linear rail and bearing set are several thousand dollars to replace, up to $10,000 AUD for the longest rail set on the Primal transfer.

The selected new lubricator system is SKF TLSD – a Electromechanical single point automatic lubricator is shown in Figure 15, Figure 16 and Figure 17.

Figure 18: Selected replacement Lubrication System SKF TLSD

During the monitoring phase the TLSD system was trialled at a processing site on LEAP III Primal and LEAP IV Middle machines for 6 months. The outcomes of the trials were that the delivery of the oil to the bearings was more consistent than the previous system and addressed all of the issues listed above.

This has allowed for reliable oil delivery to our linear shaft bearings and has an advantage of auto priming of lube lines.

The system consists of a drive unit, cartridge, and support bracket and the cost is approximately $300 per single lubricator. The new system has the advantage of easy-to-understand indicators for replacement and stoppages with simple dial to set the rate of discharge.

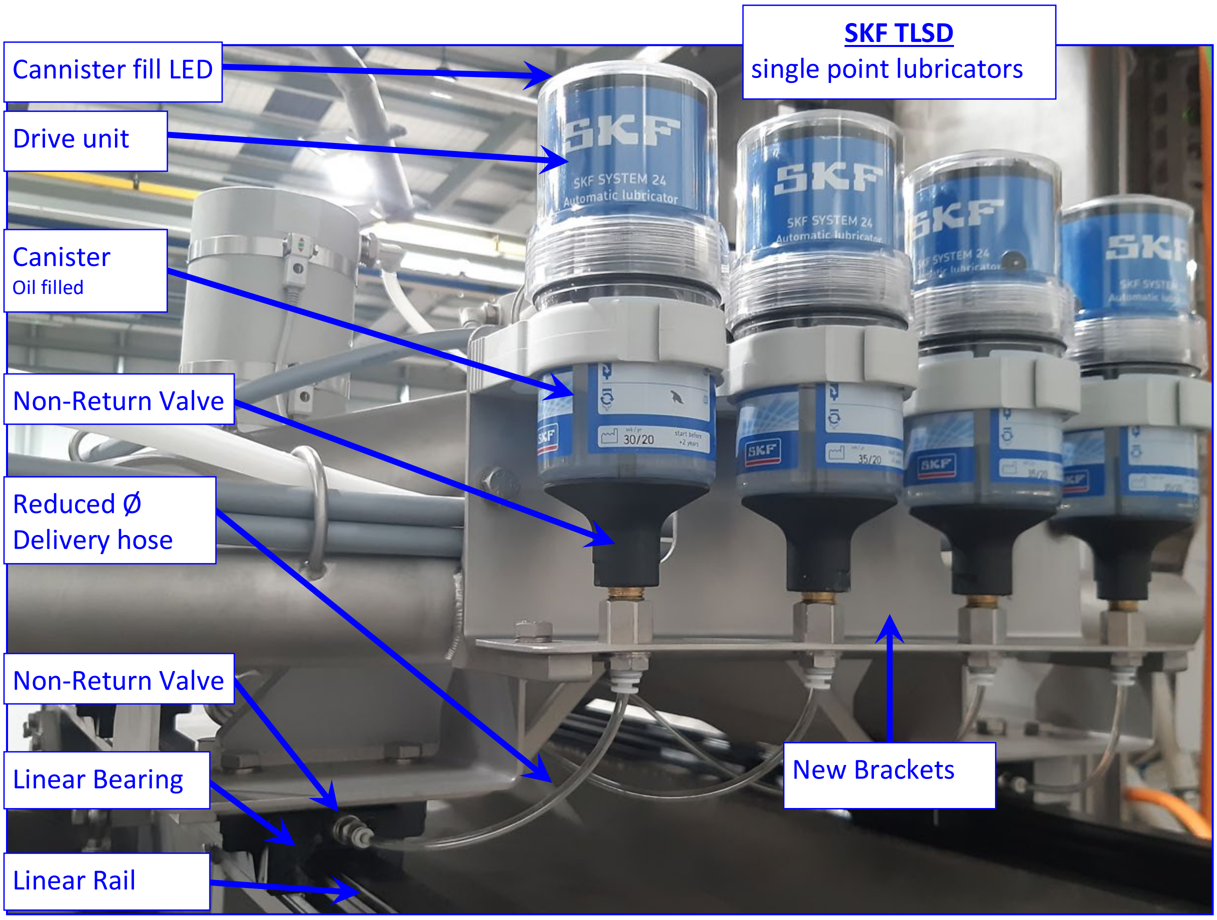

Figure 19: New single point lubrication cartridges mounted onto a Leap Primal machine Saddle station at Scott workshops.

The TLSD system also provides a visual LED indicator for the status of each lubricator where Green = good, Yellow = warning, Red = empty/faulted.

Figure 20: New Single Point Lubricators have LED status lights that flash every 5 minutes clearly indicating to the operator or maintenance staff which lubrication points require attention.

The lubrication systems has been redesigned and applied across all lubrication points on the LEAP III Primal Machine. The same principles have been applied to the LEAP IV Middle Machine, and LEAP V Forequarter machine systems with a total of 90 lubrication points across all machines.

4.5.1 Lubrication - Forequarter Tower

The LEAP III Forequarter tower (Figure 18, Figure 19) has a series of assemblies that have a high cycle rate and rely on smooth consistent motion to ensure accuracy. Equally as important, as the station is exposed to rigorous cleaning and exposure to the harsh processing environment the key moving assemblies require lubrication to ensure that corrosion and mechanical damage do not take hold and quickly deteriorate the station performance. Of note, are the vertical tower linear traverse, the cutting frame pivot and the cutting head traverse. Each of these stations required a detailed concept and design to be developed to adapt the electromechanical lubrication system.

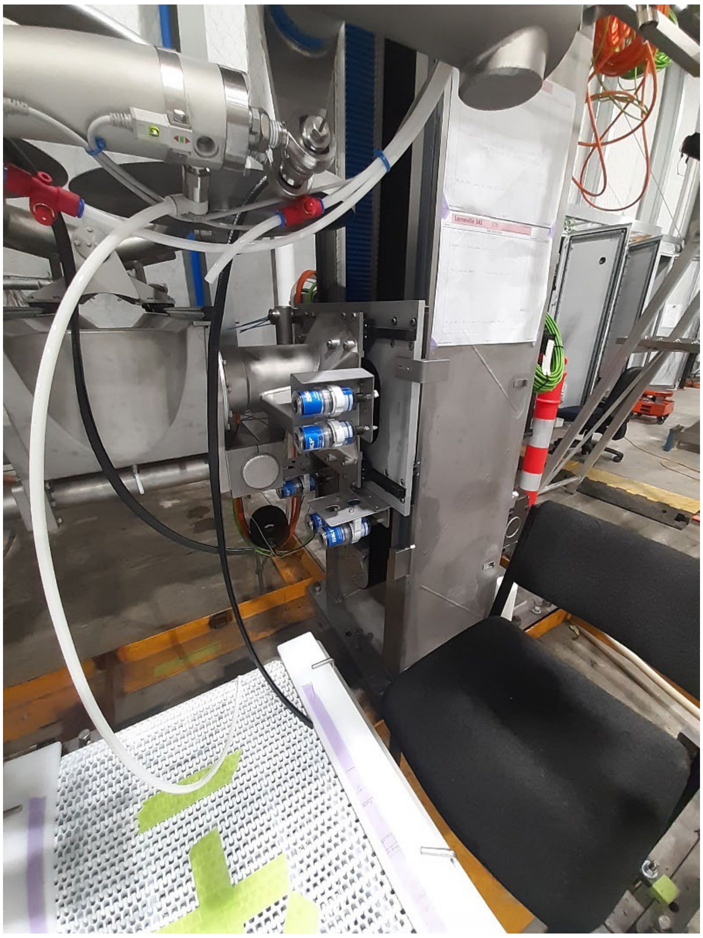

Figure 21: LEAP III Forequarter station Example of an adaption concept.

Figure 22: LEAP III Forequarter station Examples of adaption concepts throughout the cutting heads.

4.5.2 Lubrication - Saddle Tower

The LEAP III Saddle tower (Figure 20 and Figure 21) has a series of assemblies that have a high cycle rate and rely on smooth consistent motion to ensure accuracy similar to the Forequarter tower. As with the Forequarter tower, as the station is exposed to rigorous cleaning and exposure to the harsh processing environment the key moving assemblies require lubrication to ensure that corrosion and mechanical damage do not take hold and quickly deteriorate the station performance. Of note, the vertical tower linear traverse, the cutting frame pivot and the cutting head traverse. Each of these stations required a detailed concept and design to be developed to adapt the electromechanical lubrication system.

Figure 23: LEAP III Saddle station Examples of adaption concepts throughout the saddle cutting heads.

Figure 24: LEAP III Saddle station Additional examples of adaption concepts throughout the cutting heads.

4.5.3 Lubrication - Transfer

The LEAP III Transfer as shown in Figure 22 has a series of assemblies that have a high cycle rate and rely on smooth consistent motion to ensure precise movement and placement of carcases within the system. Equally as important, as the station is exposed to rigorous cleaning and exposure to the harsh processing environment the key moving assemblies require lubrication to ensure that corrosion and mechanical damage do not take hold and quickly deteriorate the station performance.

Of note, the key assemblies within the Transfer are installed at a height over 3m from floor level which makes access to lubricate manually both difficult, time-consuming and adds a working at height risk. Each of the transfer head assemblies require a detailed concept and design to be developed to adapt the electromechanical lubrication system.

Figure 25: LEAP III Transfer station showing electro-mechanical lubrication mounting arrangement.

4.5.4 Lubrication - Other key assemblies

The LEAP III system comprises a number of other assemblies that have a high cycle rate and rely on smooth consistent motion, protection from rigorous cleaning, and exposure to the harsh processing environment. Key moving assemblies require lubrication to ensure that corrosion and mechanical damage do not take hold and quickly deteriorate the station performance.

Assemblies of note as shown in Figure 23 include the imaging chain, product infeed and outfeed transfers, Forequarter integration tower assemblies, LEAP IV Middle machine integration arm assemblies, and product conveyors. A series of adaptions have been developed for each of the key assemblies and are able to be rolled out to current and future machines including any future developments.

Figure 26: Adaption module for electro-mechanical lubrication mounting for key assemblies. Single axis arrangement.

5 Conclusion

5.1 Vision analysis conclusions

Multiple paths were investigated for the vision analysis upgrade and the most promising was pursued and installed for testing at an Australian processor. A significant accuracy increase was observed in offline testing, and this was independently confirmed by Greenleaf Enterprises Pty Ltd with their findings given below.

The LEAP III Primal system conducts two automated cuts: separation of the shoulder and barrel, and separation of the barrel and legs. The system can perform additional cuts, separating the rack and loin. The current install has been operating for several years and the net benefit over manual cutting of the current install or upgraded software has been previously published elsewhere.

The variation in financial benefit for each analysis is due to measurement accuracy by the system and technology utilisation by the plant.

The higher benefit recorded for the Upgraded Software over the Current Software is because the upgraded software has improved the forequarter-rack (FQ) cutting line due to:

a. Consistent number of ribs in the FQ. Additional 12 % of FQs cut to the 4th rib
b. Accuracy of mm of meat left on the caudal end of the last FQ rib

.

5.2 Carcase stabilisation conclusions

The carcase stabilisation upgrade development has leveraged the learnings of existing system performance and advances in hardware technology. Scott have gained significant insights, knowledge, and capability in lamb carcase handling within automation systems through this work which will further improve future developments in the lamb automation space. The improved carcase stabiliser design has been successfully installed and commissioned at two LEAP Primal systems, one in New Zealand and a more recent system installed in Australia. The improved carcase stabilisation assisted in a quick sign-off of this aspect of the system on both sites and the Australian site has processed more than 400,000 products with no noticeable run-time swing.

5.3 Automated lubrication conclusions

As part of the process undertaken Scott have gained knowledge in the in the field of lubrication specifically applicable to the environment and machine requirements. Scott have applied these learnings to develop the designs to the LEAP III systems and are now able to apply these to the other LEAP IV and V systems and any subsequent system with linear moving axis. When first installed on site the new auto lubrication system was closely monitored for 6 months of production and was found to have a significantly improved delivery of the oil to the bearings was much more consistent than the previous system. Additionally, the automated lubrication system also proved to reliably discharge lubricant to the end of canisters, without air locks, and the indicator lights on the cannisters provided a clear and obvious indicator to maintenance staff when a cannister required replacing.

As with the carcase stabilisation improvements, the improvements from the auto lubrication investigation have been successfully installed in two LEAP Primal systems, in Australia and New Zealand. After their installation on both sites the lubrication upgrades were verified and shown to be working well. While their true value will be derived over a longer time period, e.g., reduced wear and tear, reduced and simplified maintenance, the auto lubrication upgrade is working as designed and should help machine reliability and maintenance significantly.

5.4 Benefits to industry

The vision analysis upgrade package provides a significant direct benefit to the customer, as independently assessed by Greenleaf Enterprises Pty Ltd. Additionally, as the vision analysis upgrade package requires no hardware changes it is an upgrade that can be quickly installed at existing sites or new installations.

The carcase stabilisation upgrade package allows increased reliability of scanning for LEAP III x-ray systems. The carcase stabilisation during x-ray scanning is a key requirement for accurate primal cutting. Any inconsistent movement or vibration during x-ray scanning will directly impact accuracy during cutting. The carcase stabilisation upgrade has been built and installed at sites in New Zealand and Australia, and at both sites there is no noticeable run-time swing. The carcase stabilisation upgrade is retrofittable to existing LEAP III machines and will be part of new LEAP III machines going forwards, allowing accuracy benefits for both current and future industry partners.

The automated lubrication upgrade package was designed to improve the reliability of the existing lubrication system. Feedback from industry partners indicated that:

- Premature failure of lubrication cartridges can cost system owners a substantial amount to replace.
- There is significant labor savings from having a reliable lubrication system as this allows maintenance to attend to other requirements while the Scott lamb Primal system continues in production.

The automated lubrication upgrade was monitored closely for six months and was found to deliver oil at a much more consistent rate that the current system. The upgraded system addressed the primary causes of premature failure of lubrication cartridges, namely, the piston no longer moving or discharging grease, and air locks in the delivery line and in the canister. Additionally, the lights on the cannisters of the upgrade now provide a clear and visible sign for the maintenance team to replace canisters as soon as they are empty, thereby extending the lifetime and improving the reliability of the machine.

6 Future research and recommendations

Significant improvements have been achieved in this project. Given the improvements over the current systems the carcase stabilisation and automated lubrication packages are now standard in future LEAP III primal systems and the analysis upgrade is available as an optional upgrade to provide additional benefit to the customer.

During this project several future improvements were identified including:

- Additional data labelling for the AI analysis. Current neural networks can achieve super-human labelling results if provided enough training data from a pool of manually labelled data. While significant improvements were achieved with the current data set, increasing the size and variability of the data set would likely increase the performance of the system. An automated labelling system as proposed in the point above would be one option to obtain more data but would require significant research and development while additional manual labelling is more quickly attainable in the short term.
- Centralisation of parts of the lubrication system. The current lubrication upgrade solves many of the problems of the current lubrication system. However, it still requires dozens of individual canisters spaced throughout the machine, all of which require monitoring and replacement. An investigation into a larger reservoir system for elements of the lubrication system could cut down on this complexity and allow simpler maintenance.
- Automated lubrication warnings. An important benefit of the lubrication upgrade was the warning lights which notify maintenance staff of empty canisters. This is a consequential improvement from the current system where maintenance staff must assess the levels of the clear lubricant within the clear canister. A further improvement would be outputs from the lubrication's canisters to the PLC. This would allow the maintenance staff to get a notification from the machine HMI about which lubrication canisters require replacement, thereby further improving the servicing time of the machine.