final report

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JBS Dinmore Beef Rib Cutting
MLA Public Report

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Executive Summary

Beef rib cutting is a typical case where current manual tasks can be replicated by an automated system. The major benefits of this automation are increased yield and the positive impact on critical industry OH&S issues.

The beef rib cutting operation at JBS Dinmore was performed manually, requiring two operators per shift using hydraulic saws which are dangerous tools offering significant OH&S risks and potential for serious injuries such as amputations due to the physical nature of the task and effort needed to operate them even with operator aids. This task is arduous to all operators and due to the requirement of accuracy to maximise yield cannot be performed by an unskilled person.

The requirements of the automated system are to:

- Stabilise the carcass;
- Scan the carcass with all required sensing technologies;
- Process the sensing data to identify the start and end points of each cut;
- Communicate this cut data to a robot which will perform the cut using a beef cutting tool;
- Cut through the designated ribs without damaging underlying muscles;
- Identify carcasses by grade to ensure specification compliance and maximum yield achievement at maximum speed;
- Operate at chain speeds up to 520 sides per hour moving into the system;
- Be able to deal appropriately with chain stoppages.

The system performs two cuts. The brisket cutting line is determined by the x-ray finding the cartilage junction between rib #1 and sternum bone #1 to an imaginary point approximately 25mm off the point of the ileum. The second cut is made parallel to the first cut. The distance between the two cuts depends on the grade of the carcass. This is determined from the information contained in the RFID tag in the beef roller.

The automatic rib cutting system is fully operational and is used for production at JBS Dinmore. It is operating at 520 sides/hour and has replaced two skilled operators per shift. The accuracy of the cuts has been demonstrated to be 97% within specification. This is significantly better than can be achieved via manual processing. A cost benefit analysis is to be performed by an independent organisation (Greenleaf) which will quantify the benefit to industry of this system.

The developments in sensing and X-ray technology, new stabilisation conveyor backing board and blade selection/profile (such that bone fragments are reduced and correspondingly yield is increased) are all suitable for further application and use in red meat automation.

With the completion of the Project, SCOTT Automation have completed the following to JBS and MLA's satisfaction:

- Manufacture, supply, development, installation and commissioning, of a Robotic Beef Rib Cutting System for JBS, Dinmore plant,
- Develop and introduce new sensing and X-ray technology suitable for further application use for red meat automation.
- Develop and introduce new stabilisation conveyor backing board suitable for further application use for red meat automation.

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1 Background

1.1 Project Background

Beef scribing refers to the first cuts that are made to a side of beef, before it enters the boning room. These cuts are typically the boundary between high value and lower value products and hence correct placement significantly impacts the yield.

This task is usually performed by operators using hand held circular saws. It is an arduous, hazardous task and the accuracy required to maximise yield means it cannot be performed by unskilled operators.

Semi-automated beef scribing, project P.PSH.508, took a camera image of a side. An operator at a computer terminal identified the robot start and end points for each scribe cut by clicking the image with a mouse. The resulting semi-automated system was capable of processing 340 carcases a day. Whilst this was not an acceptable solution for high volume production, it showed that with further development an automated solution was possible.

A further project to produce a fully automated X-ray based system was conceived. This project was split into two stages – P.PIP.0261 Beef Rib Cutting Stage 1 and P.PIP.0288 Beef Rib Cutting Stage 2.

Stage 1 included all the preliminary design, development and trials of key system components. Stage 2 (this project) continued the development, including major component purchase, building works, manufacture, supply, installation and commissioning of the system at JBS Dinmore.

Two subsequent projects were also undertaken PSH.0620 and PSH.0633 following X-ray calcification trials and multiple X-ray carcass trials, which highlighted a need for additional X-ray equipment, additional software development and changes to safety requirements, stabilistation mechanism and system layout.

1.2 System Principle

The beef rib cutting operations at JBS Dinmore were performed manually, by two operators per shift, using hydraulic saws. These saws offer significant OH&S risks (ie.strain/sprain injuries, Muscular Skeletal Disorder) and potential for serious injuries such as amputations. Due to the physical nature of the task significant effort is needed to operate them even with operator aids.

The robotic beef Rib Cutting System replicates the actions of the manual saw operators and provides an automated process with the following features and benefits:

Features & Benefits:

- **Line Speed –** *520 beef sides/hour*
- **Labour Reduction –** *2 operators per shift*
- **OH&S –** *Elimination of dangerous operational task*
- **Productivity –** *Ensures improved cut surface finish compared to manual operations*
- **Efficiencies –** *Accuracy of cuts reduce need for rework*
- **Yield Gain –** *Consistent accuracy of cuts will provide significant yield gain*
- **Hygiene –** *Reduced contamination compared to manual operations*

The cuts themselves are separated into two specifications:

Cows/Bulls:

- Ribs 2-8 to be cut (partial overcut onto ribs 1 and 9 possible)
- Width between both cuts to be approximately 225mm, with a minimum of 200mm
- Minimum body weight is 90kg/side

Steers:

- Ribs 2-8 to be cut (partial overcut onto ribs 1 and 9 possible)
- Width between both cuts to be approximately 160mm
- Minimum body weight is 100kg/side

Reliability and accuracy, along with processing speed were critical to the success and acceptance of this technology

2 Project Objectives

2.1 System Scope

The project objectives as worded in the research agreement are as follows:

With the completion of the Project, SCOTT Automation have completed the following to MLA's satisfaction:

- Manufacture, supply, development, installation and commissioning, of a Robotic Beef Rib Cutting System for JBS, Dinmore plant,
- Develop and introduce new sensing and X-ray technology suitable for further application use for red meat automation.
- Develop and introduce new stabilisation conveyor backing board suitable for further application use for red meat automation
- Full documentation including schematics and manuals
- System videos, reports and documentation detailing the system, its components and operational procedure to be provided for industry dissemination and promotional purposes

The project objectives as worded in the subsequent research agreements (PSH.0620 and PSH.0633) are as follows:

The project will achieve the following above that allowed for within P.PIP.0288:

1. X-Ray Data Acquisition Software Development:
Working with the X-ray Supplier, SCOTT Automation developed additional x-ray data acquisition software, which has increased in scope based on recent trials (P.PIP.0288) to accommodate x-ray setup and to meet the new beef scriber specification requirements determined during recent trials.

2. X-Ray Integration & Software Development
SCOTT Automation will develop additional integration software between the x-ray, 2D vision system and robot controller which has increased in scope based on recent trials to accommodate wide angled x-ray setup and to meet the new beef scriber specification requirements determined during recent trials.

3. Mechanical Design associated with new X-Ray system and changes to system layout
The layout of the Beef Rib Cutting system has changed due to new x-ray requirements and further production consideration by JBS Australia (see proposed system layout below). This new layout has

considerations for stabilisation, safety, x-ray screening, x-ray fixturing, beef side production bypass, beef side buffering, O/H rail and stabilisation conveyor changes associated. Detailed design changes for manufacture must reflect this new system layout.

4. Additional X-Ray Tube and generator hardware associated with introduction of two tube wide angled dual energy x-ray setup to analyse complete beef side and as per new design. Recent trials have determined actual power ratings and the wide angled setup to cover the complete beef side incurs significant additional cost to previous budgets. Includes two 90deg 4kW wide angled tubes and 3kW generators.

5. Additional X-Ray Detector hardware associated with the introduction or a wide angled tubes requiring larger detectors with a 1.6mm resolution to cover complete beef side and as per new design Introduction of the wide angled dual energy setup requires high/wider angle tubes and larger detectors from other methods evaluated, however overcomes the need to use a 4 tube setup and mitigates the need for more complex algorithms for image stitching and interfacing producing a more reliable easier maintained and developed system allowing for improved accuracy and capacity to meet production rates however incurs additional cost to previous budgets.

6. Additional X-Ray hardware to fix and secure wide angled tubes and larger detector system as per new design

7. Additional Robot Safety and Lead Shielding as per new design, introduction of wide angled tube/detector dual energy system has led to changes in design to maintain safety requirements.

8. Changes to O/H Conveyor System to suit new design to accommodate changes to XRay, safety, beef side buffering and bypass requirements.

9. Changes to Stabilisation Conveyor System to suit new design which includes integration of X-ray detectors and additional nonconductive conveyor belt system and conveyor section design.

10. Changes to beef side stabilisation entry and exit to suit new design and accommodate changes to x-ray, safety, beef side buffering and bypass requirements.

11. Additional X-Ray Integration, software, setup and testing
The new design and additional components have led to an increase in the allowance for integration setup and testing of equipment by SCOTT Automation with the assistance of AST.

12. Documentation & Reports

3 Methodology

3.1 Machine Description

The Rib Cutting System accurately performs the rib cutting procedure on sides of beef at a rate of up to 520 sides per hour.

A combination of X-ray, vision and laser sensing technologies are employed to determine the rib and aitch bone positions and then calculate the optimum cut angles and placements achievable in order to obtain the greatest yield from the carcass.

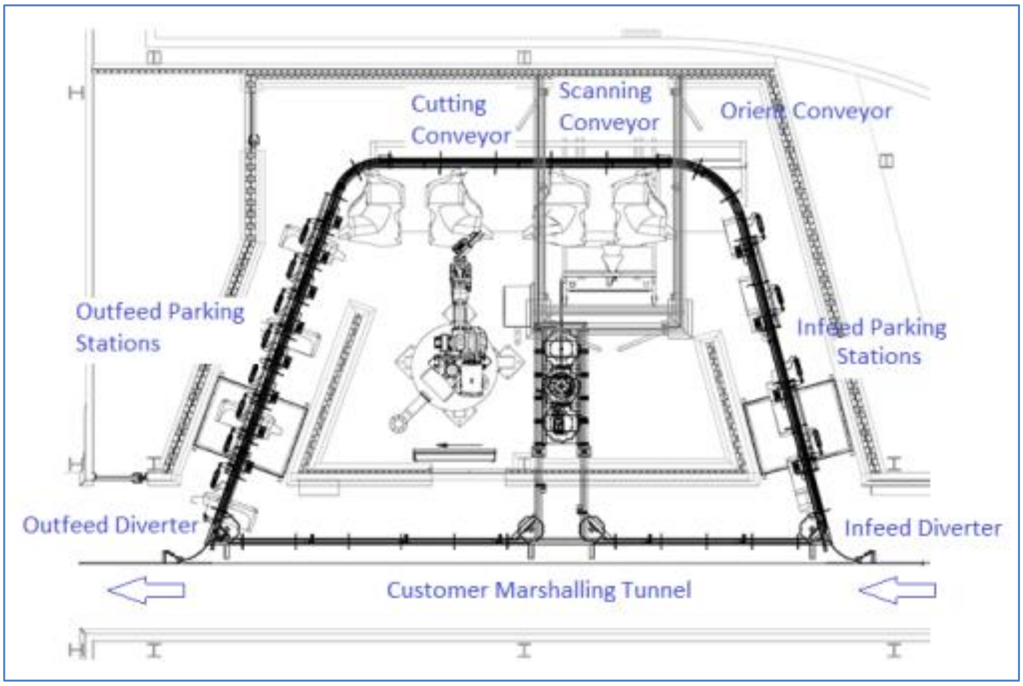

Fig 1: 2D System Layout

Fig 2: 3D System Layout

3.1.1 Marshalling Tunnel Conveyor

The marshalling tunnel conveyor is the customer supplied conveyor that feeds unprocessed sides into the rib cutting cell and accepts processed sides from the cell. The rib cutting cell takes control over the marshalling tunnel conveyor whenever it is in production mode, however this line can still be inhibited via the latching stop and E-Stop buttons found along the length of the conveyor.

The speed and position of the marshalling tunnel conveyor is tracked using sensing mounted on the driven sprocket of the conveyor. The speed of this conveyor is periodically sped up or slowed down in order to maintain synchronisation with the overhead chain conveyor of the rib cutting cell.

Fig 3: Marshalling Tunnel Conveyor

3.1.2 Overhead Chain Conveyor

The conveyor operates at approximately 220mm/s and the position of the conveyor is continuously tracked in real time using an encoder in order to facilitate integration between the vision system and industrial robot.

Fig 4: Overhead Chain Conveyor Sprocket and Drive

3.1.3 Infeed Diverter Station

The infeed diverter station is used to divert unprocessed sides of beef from the customer's marshalling tunnel conveyor and into the rib cutting cell for processing. When the system is in Maintenance mode, sides bypass the rib cutting cell and are manually processed.

The infeed diverter station consists of a diverter plate, feeder arm with retractable finger, and guide rail.

The infeed diverter station transitions between 'divert' and 'bypass' modes depending on the operating state of the system.

Fig 5: Infeed Diverter Station

3.1.4 Infeed Parking Stations

These are buffering stations, the purpose of which is to allow the rib cutting system to continue processing sides when the main chain stops. The aim is to allow all product that has reached the stabilisation conveyor (orient, scan, cutting conveyors) to continue on through the system. Starting and stopping of the stabilisation conveyor/rib cutting system overhead chain is not desirable due to possible side movement/slippage when the conveyors stop/start.

Unprocessed sides that are on the way into the system will be buffered before they reach the stabilisation conveyors at the four Infeed Parking stations. Pneumatic cylinders are used at each parking station to inhibit movement in the hooks along the chain and raise the overhead chain above the hooks. All four infeed parking stations actuate simultaneously when the system is stopped or started.

Product in the infeed tunnel is parked at one of the four infeed parking stations when:

1. The marshalling tunnel conveyor is stopped; or
2. The rib cutting cell is stopped.

Fig 6: Infeed Parking Stations

3.1.5 Orient Conveyor

Unprocessed sides are transitioned onto the angled orient conveyor prior to imaging. The orient conveyor eliminates unwanted swing and stabilises the carcass prior to image capture and processing.

3.1.6 Scanning Conveyor

The unprocessed sides are transitioned from the orient conveyor onto the scanning conveyor using a driven hex roller. The hex roller minimises carcass movement during the transition between the orient and scanning conveyors. This provides optimal image quality by the image acquisition system.

The scanning conveyor is a belt driven conveyor which allows the carcass to be imaged by the X-ray, vision and scanning systems without inducing unnecessary interference. The X-ray detectors are housed behind the scanning conveyor.

The beef sides are then transitioned from the scanning conveyor onto the cutting conveyor using a driven hex roller. The hex roller minimises carcass movement during the transition between the scanning and cutting conveyors.

The Orient-to-Scan and Scan-to-Cut hex rollers are generally energised whenever the scanning conveyor is running.

3.1.7 Cutting Conveyor

The cutting conveyor is a dual belt system which consists of multiple interlocked boards to facilitate maintainability.

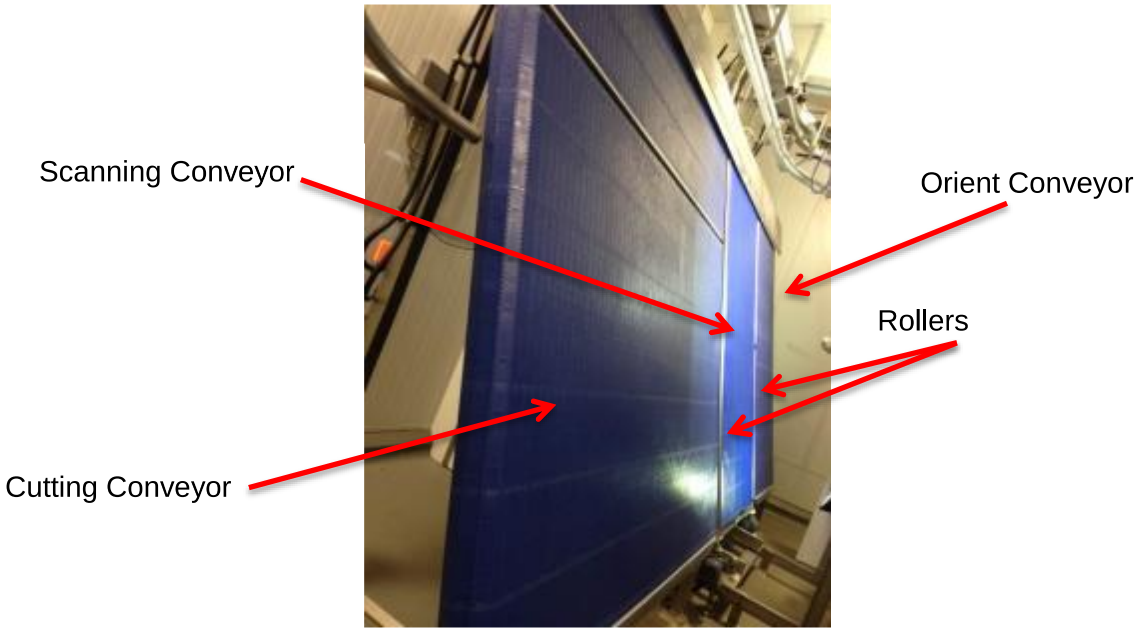

Fig 7: Orient, Scanning and Cutting Conveyors

3.1.8 Outfeed Parking Stations

These buffering stations allow the system to cater for unplanned stoppages by storing the sides that have already passed through the cutting station and are on the way out of the system, thus preventing sides being fed onto a stopped marshalling tunnel line. Processed product in the outfeed tunnel is parked at one of the eight outfeed parking stations when:

1. The marshalling tunnel conveyor is stopped; or
2. The rib cutting cell is stopped.

The system is designed to allow all unprocessed sides that have reached the stabilisation conveyor (orient, scan, cutting conveyors) to continue to be processed through the system, rather than be automatically passed through the system unprocessed, hence minimising the amount of unprocessed sides travelling through the rib cutting system.

As at the infeed parking stations, pneumatic cylinders are used at each parking station to inhibit movement in the hooks along the chain and raise the overhead chain above the hooks.

Fig 8: Outfeed Parking Stations

3.1.9 Outfeed Diverter Station

The outfeed diverter station is used to divert sides of beef back onto the customer's marshalling tunnel conveyor after processing.

The outfeed diverter station consists of a diverter plate and feeder arm with retractable finger.

When the system is in Maintenance mode, sides bypass the rib cutting cell and are manually processed. The outfeed diverter station transitions between 'divert' and 'bypass' modes depending on the operating state of the system.

Fig 9: Outfeed Diverter Station

3.1.10 Industrial Robot

An ABB industrial robot with saw motor actuator is employed to perform the rib cutting operations. A blade guard, fitted to the saw, limited the distribution of debris around the cell.

The robot is fitted with an inflatable protective suit to protect it from water ingress during wash down.

The controller used to command the robot is located in the control room. The sock blower used to inflate the protective suit is mounted above the robot controller.

Fig 10: Industrial Robot

3.1.11 Operator Panel

The operator panel is where the primary interfacing with the Rib Cutting System is performed. Generic system controls and feedback are located on this panel.

Fig 11: Operator Panel

3.1.12 HMI Panel

The HMI panel is where advanced interaction with the Rib Cutting System is performed. Detailed information regarding the system state, fault status, cut profile and so forth is displayed.

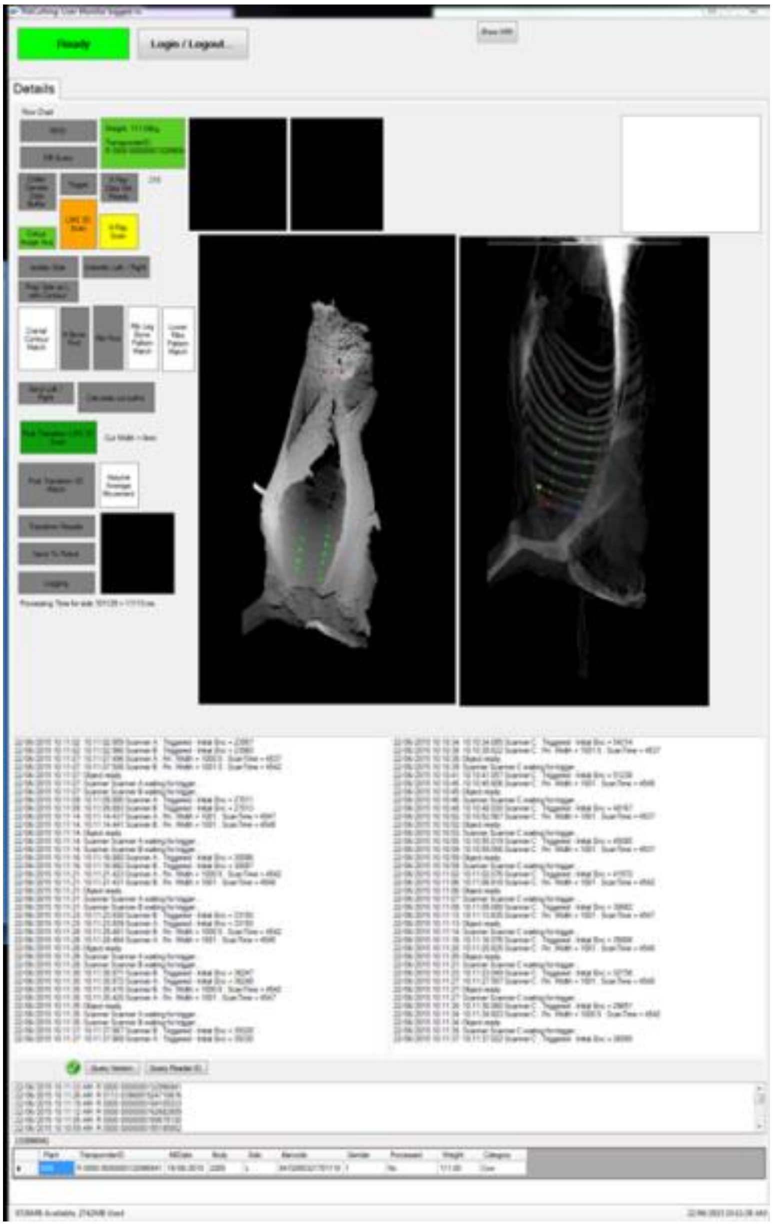

Fig 12: HMI Panel Screen 1

Fig 13: HMI Panel Screen 2

3.1.13 Sterilisation Tank

The wash tank is used to sterilise the saw blade throughout the day. The blade sterilisation process must be manually initiated and can be done by either the ‘Blade Sterilise’ pushbutton on the operator panel or the ‘Robot Status’ then ‘Sterilise’ soft keys on the HMI. The sterilisation process consists of a 60 second hot wash followed by a 10 second cold wash. Real-time temperature feedback from the wash tank is displayed on the digital readout display mounted on the operator panel.

The wash tank also contains a blade calibration system which is mounted on the side of the wash tank. Whenever the robot is moved to the service position or out into manual mode, a blade calibration request is flagged. This routine is used to ensure that the blade diameter is within the system’s allowable working limits and that the robot tool paths are appropriately offset from the carcass on the cut conveyor.

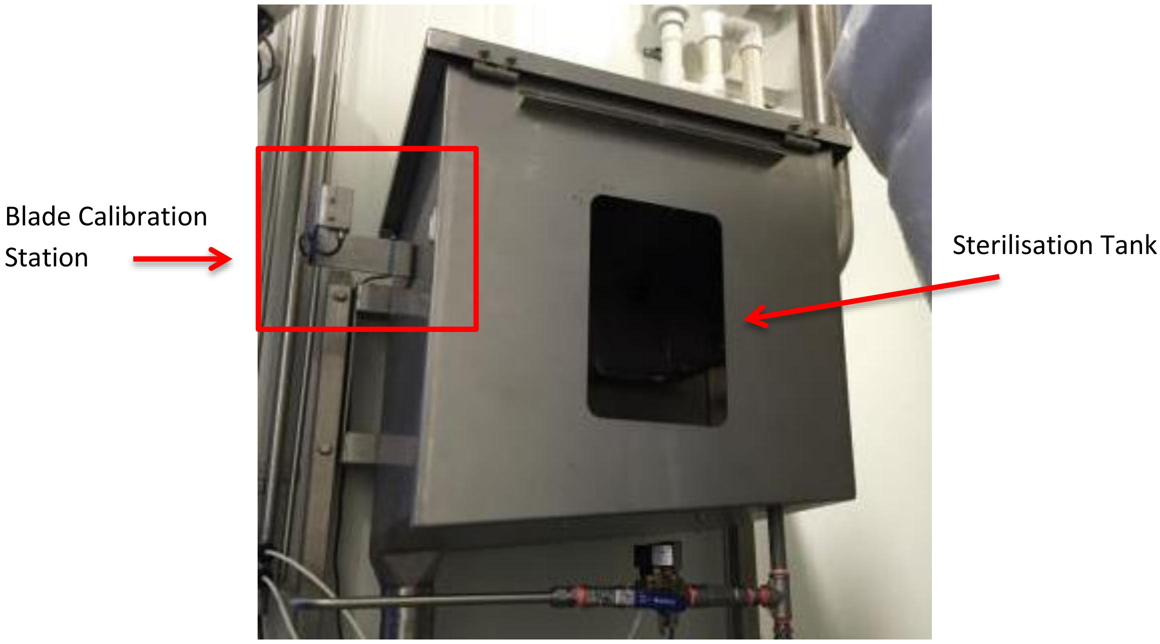

Fig 14: Sterilisation Tank and Blade Calibration Station

3.1.14 Vision System

Carcass data is captured using a collection of X-ray, colour camera, and laser measurement technologies. This information is transferred back to the Vision PC for processing. Processed data, in the form of way points, are then transferred to the robot controller in order to perform the cutting operations.

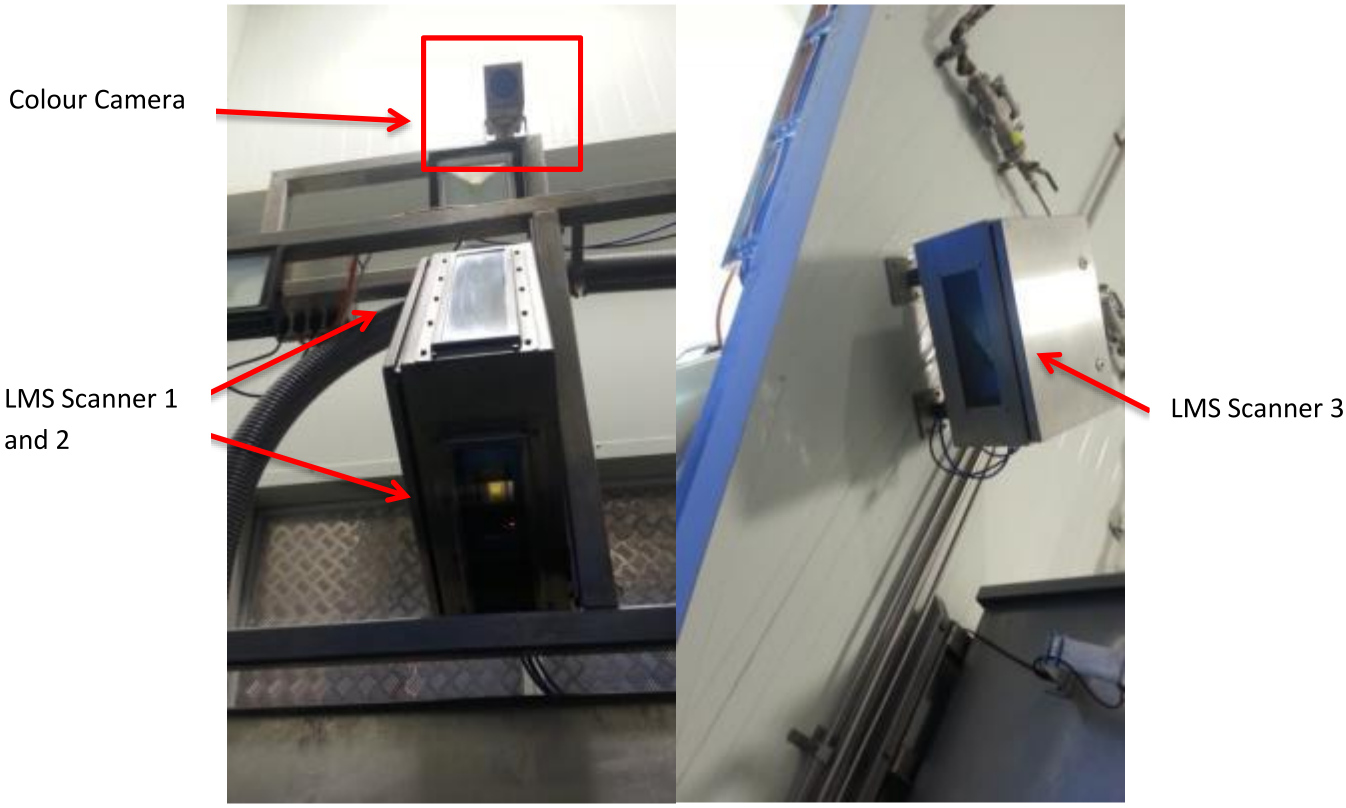

Fig 15: Colour Camera and LMS Scanners 1, 2, and 3

The X-ray capturing system utilises a number of sub-systems which are essential to ensure that the images produced are of high quality. These subsystems include:

- Generators (2 off);
- Dehumidifier;
- Water Chiller;
- Control Cabinet; and
- Control PC.

Each one of these subsystems must be ON and operational in order for the system to operate.

Fig 16: X-ray Image Acquisition

Fig 17: Vision System – Colour Camera Results

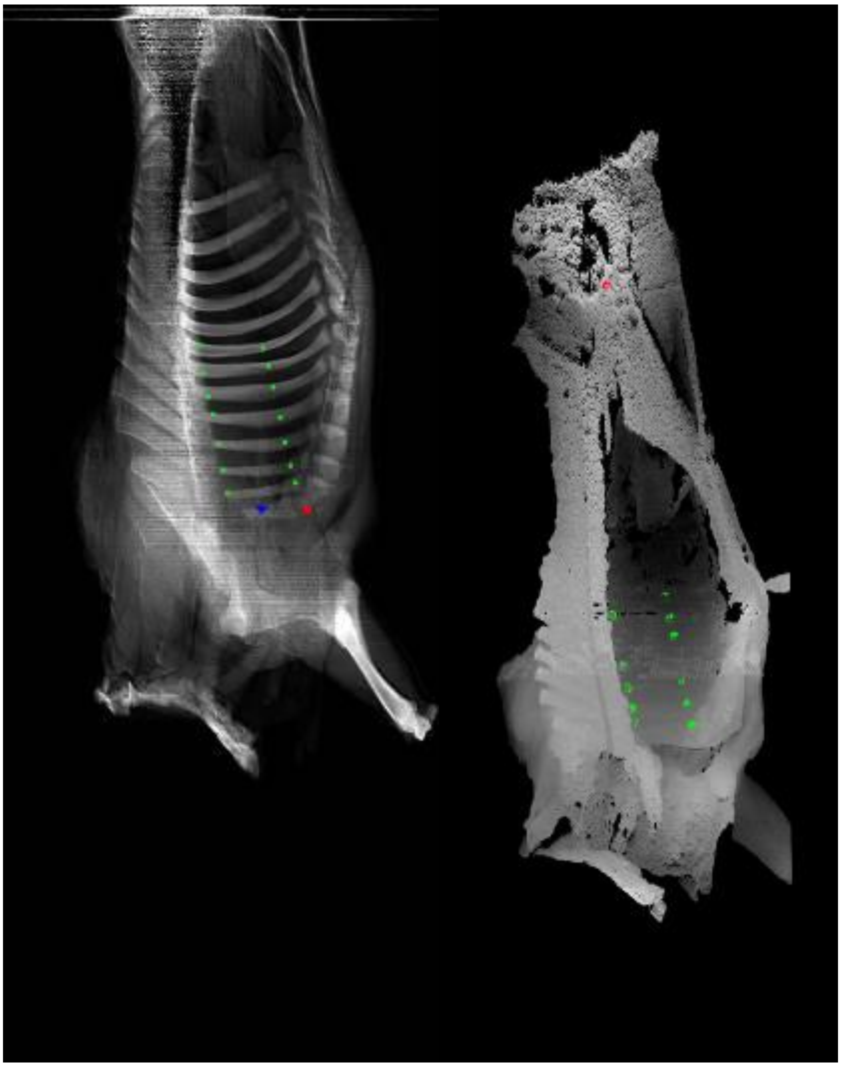

Fig 18: Vision System – X-ray and Point Cloud Images with Cut Path Overlay

4 Results

4.1 Trials

Production trials were first conducted completely supervised. For several weeks, SCOTT staff were on hand to abort a cut in the event that the vision software behaved unpredictably, which could have resulted in extensive damage to the robot, saw blade, or cutting conveyor. During this period, statistics were also gathered to determine the root cause of improperly processed sides. This period also allowed SCOTT engineers time to address various unforeseen failure modes that could only be ascertained from running the system in a production setting.

As operation of the Rib Cutting System became more predictable and reliable, production was steadily ramped up. This ramping up process allowed SCOTT to ensure the system was able to accommodate the increased operating times and also gauge the longevity of the saw blade throughout the day.

At present, the system is operating completely unsupervised in full production mode at a line speed of 520 sides per hour. The robot and vision system is able to keep up with the cycle time requirements of the project; even whilst processing larger carcasses. It is unlikely that system will be able to increase the throughput to greater than 520 sides per hour without significant reworking to the cell.

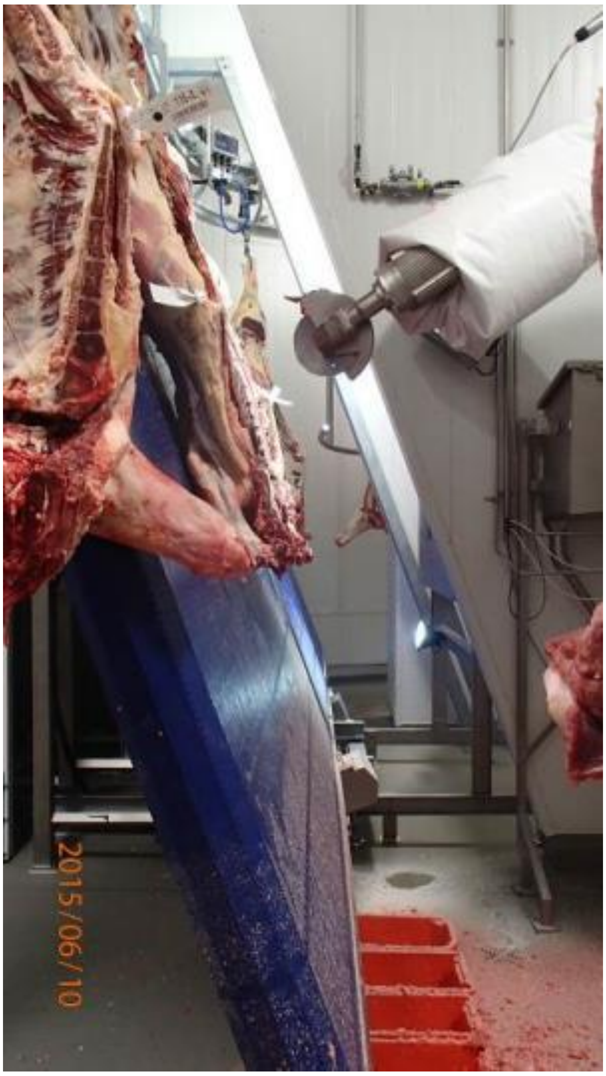

Fig 19: Robotic Cell Processing Sides

4.2 Verification

Processed sides were physically verified by SCOTT and JBS staff in lots of 100 carcasses over the production trial period. This allowed both parties to assess the cut quality over time and gave SCOTT critical feedback in order to make iterative improvements to the vision processing and cutting algorithms.

By the end of the verification process, it was observed that over 97% of sides were processed within JBS' cutting specification. The remaining sides were either cut slightly outside of spec, or not processed.

5 Discussion

5.1 Limitations

Identified as possible failure modes during the initial scoping phases of the project, and verified through multitudes of on-site trials, the bulk of the missed and / or defective cuts can be attributed to the following issues, all below items being outside the scope of Scott tasks:

- Flipped sides;
- The presence of Longus Colli muscle;
- Pre-processed sides (including Strung necks/legs).
- Double ups

5.1.1 Flipped Sides

Carcasses must enter the cell in the correct orientation. That is, the carcasses are to enter such that the outside of the carcass is touching any stabilisation bars / conveyors and the chest cavity is facing the sensing equipment and robot. Carcasses oriented incorrectly will fail during the carcass analysis phase and will remain uncut.

Fig 20: Flipped Side at the Scanning Conveyor

5.1.2 Longus Colli

The longus colli muscle runs along the ventral aspect of the cervical and thoracic vertebrae up to the 6th rib. As part of normal processing procedures and carcase specifications, this muscle is meant to be pulled to below the first rib. The vision algorithms were thus coded with this in mind. There can be times during production runs where this muscle is not pulled or not pulled correctly however. Production trials have verified that the presence of the Longus Colli muscle yields unpredictable results in the vision analysis module. Site has been working to address this issue by refining practices in their upstream carcass dressing procedures – either by completely removing the longus colli muscle or ensuring it is removed to a point below the rib 1 junction.

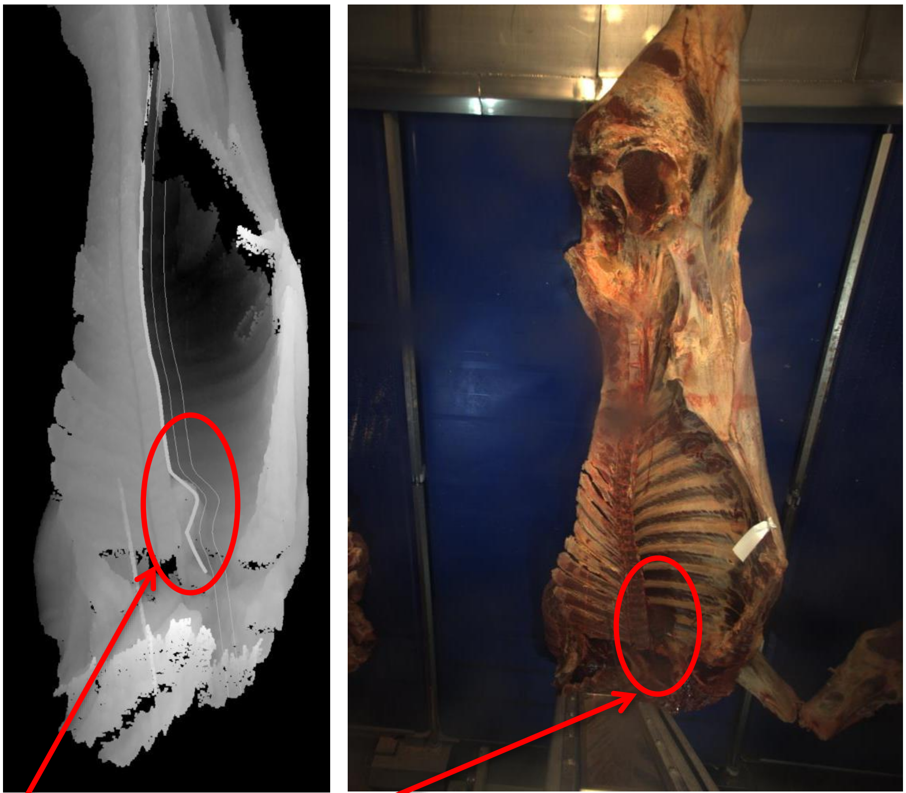

Fig 21: Side with Longus Colli Present

Longus Colli Artefacts

5.1.3 Pre-processed Sides

A defective side has been defined as a side with:

- Removed chunks of bone / flesh;
- Inclusion of foreign objects (tags, hooks, etc.); or
- Strung necks / legs.

These sides are generally presented differently from the default form and can drastically affect the vision analysis software. Although these sides are outside the carcase trim specifications of the system, an attempt will still be made to place a valid cut.

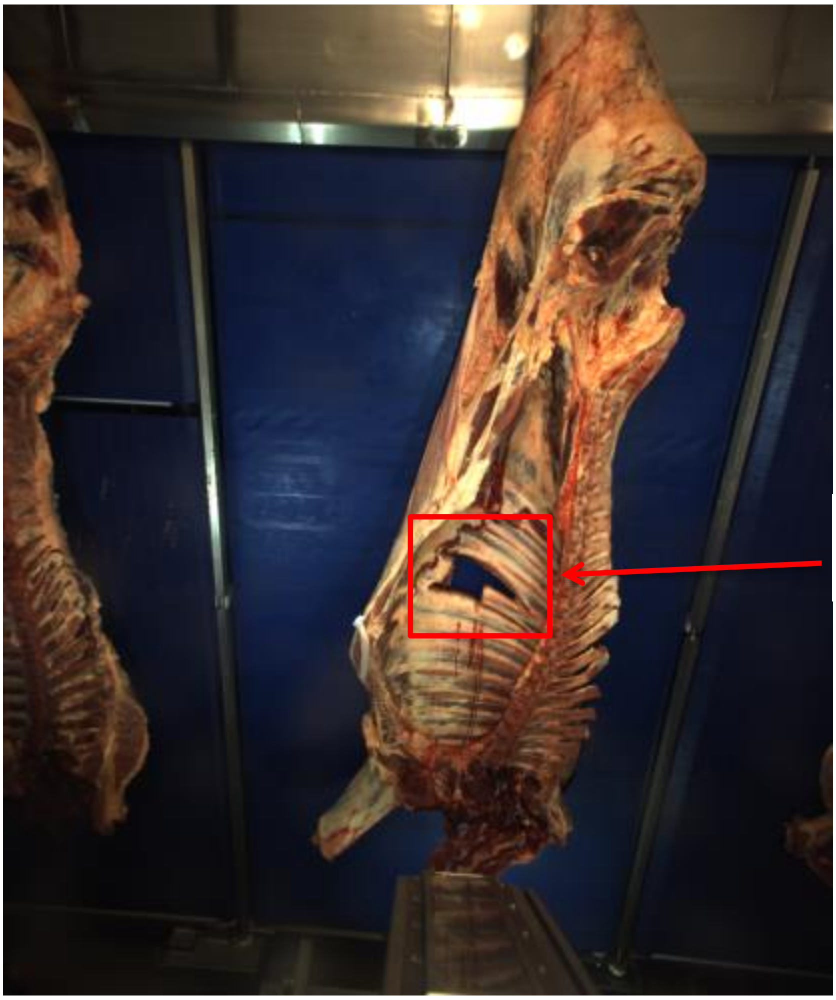

Figure 22: Side with ribs partially removed.

5.1.4 Double Ups

'Double Ups' are defined as two sides travelling through the cell on the same overhead chain attachment. These instances typically occur when an operator feeds the side from the chiller onto the main conveyor line. The control system has been programmed to detect these instances and leave them uncut.

Figure 23: Double Up at the Scanning Conveyor

6 Conclusion

With the completion of the Project, SCOTT Automation have completed the following to JBS and MLA's satisfaction:

- Manufacture, supply, development, installation and commissioning, of a Robotic Beef Rib Cutting System for JBS, Dinmore plant,
- Develop and introduce new sensing and X-ray technology suitable for further application use for red meat automation.
- Develop and introduce new stabilisation conveyor backing board suitable for further application use for red meat automation.

The introduction of the robotic rib cutting system at JBS, Dinmore has yielded the following features and benefits and deliverables:

- **Labour Reduction –** *2 operators per working shift*
- **Line Speed –** *520 beef sides/hour*
- **OH&S –** *elimination of dangerous manual operations*
- **Productivity –** *ensures improved cut surface finish compared to manual operations*
- **Efficiencies –** *accuracy of cuts reduce need for rework*
- **Yield Gain –** *consistent accuracy of cuts will provide significant yield gain*
- **Hygiene –** *reduced contamination compared to manual operations*

The system is currently operating completely unsupervised in a full production setting at a line speed of 520 sides per hour. The robot and vision system are able to keep up with the cycle time requirements of the project; even while processing larger, more geometrically complex carcasses.

The system has been independently verified and validated on multiple occasions. It was observed that over 97% of sides were processed fell within JBS' cutting specification. The remaining sides were either cut slightly outside of spec. or not processed.