Final Report

Beef Modular Side Processing – Module #2 and #3 – Chine & Square Cut Cube Testing & Trials

Public Report

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Prepared by
J. Cook, L. Parsons, A. Martchenko, T. Enfield, A. Pipala, S. Ali

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1.0 Abstract

Chine removal and the cuts used to produce a Square Cut Cube Roll are currently performed manually in beef-processing plants. These tasks require skilled labour, expose workers to knives and powered saws, and can reduce the recovery of valuable meat when cuts are not placed accurately. This project investigated whether robots could perform these operations safely, consistently and with sufficient accuracy to support development of a production system.

A robotic trial was performed at Kilcoy Global Foods to evaluate the automation of these tasks. Different tooling designs, cutting methods, support arrangements and camera-guided cutting paths were developed and tested on beef sides. The work progressed through repeated trials, with the equipment and cutting methods adjusted in response to the results. The final results of the work for both tasks were demonstrated to AMPC and KGF at the end of the project. A high-volume trial was also performed for the chine removal task to confirm yield benefits, as well as the ability for downstream deboning tasks to capture these benefits.

The project successfully demonstrated both operations on stationary beef sides. The trials established practical requirements for tooling, stabilisation, equipment calibration, blade management and product handling. A method for comparing yield against the existing process was developed, and the trial confirmed that the resulting product could be processed downstream to capture the intended yield benefit.

The results address the main technical feasibility risks and provide sufficient confidence to progress to a production-scale research and development project. Successful production implementation could improve worker safety, reduce reliance on skilled manual labour, improve consistency and protect the recovery of high-value meat.

2.0 Executive summary

This project investigated whether two beef-processing tasks - chine removal and the production of the Square Cut Cube Roll - could be performed robotically. Chine removal involves cutting the chine bone away from the cube roll, while Square Cut Cube Roll production involves extending two existing scribe cuts through the eye muscle to create accurate faces on both ends of the cube roll. These tasks are currently performed manually and require skilled labour. They also expose workers to knives and powered saws, and can reduce recovery of valuable meat when cuts are inconsistent. The results were intended to determine whether the technology was ready to progress from controlled trials to a production-scale research and development project.

The project had two main objectives. First, it aimed to demonstrate robotic chine removal on stationary beef sides and confirm the required cutting tool, robot, camera system, product support and operating method. Second, it aimed to demonstrate robotic Square Cut Cube cutting and confirm the same key system requirements. Both objectives were achieved. The project also updated the proposed production concept and identified the work required for a future production implementation.

The work was completed through a staged testing program and hosted at Kilcoy Global Foods' Kilcoy plant. A robot, cameras, product-support equipment, control systems and prototype cutting tools were designed and installed in a dedicated chilled trial area. Different tooling concepts, product-support arrangements and camera-guided cutting paths were tested and refined through repeated trials. The program progressed from manually taught robot movements to cuts adjusted for the size and shape of each beef side, followed by medium- and higher-volume demonstrations and downstream assessment in the boning room.

The project successfully demonstrated both robotic processes. For the Square Cut Cube Roll task, a robot-mounted tool produced the required cuts with clean and consistent faces. For chine removal, a custom robot-mounted tool successfully removed the chine using a cutting path adjusted for each carcase. The project also identified important production requirements, including accurate setup, tool monitoring, product positioning, and controlled handling of the removed chine. A practical yield-assessment method was established using robot-cut sides and corresponding control sides, and the trials confirmed that the changed product presentation could be processed downstream to capture the intended yield opportunity. The high-volume chine removal trial calculated a significant yield benefit and also confirmed the product was able to be boned out effectively and produce a well-presented product.

The results provide a credible pathway to automate tasks that currently involve significant manual cutting and safety risk. Potential industry benefits include improved worker safety, reduced dependence on skilled manual labour, more consistent cuts and better protection of high-value meat recovery. The main technical feasibility risks were addressed sufficiently to support progression to the next stage.

It is recommended that AMPC, Kilcoy Global Foods and Intelligent Robotics proceed to a production-scale research and development project that integrates the new modules with the existing IR-SCRIBE system. That project should validate repeatability, cycle time, reliability, cleaning, tool life, operator interaction and yield over sustained production volumes. Broader industry adoption should follow once production performance and the commercial case have been demonstrated.

3.0 Introduction

The Australian red meat processing sector continues to rely heavily on manual labour for many complex cutting and separation tasks. While automation has been successfully introduced into selected parts of the processing chain, a number of high-value operations remain difficult to automate because of natural variation between carcases, the need for accurate sensing and cut-path definition, and the requirement to manipulate cutting tools safely and consistently. This project addressed two such operations: removal of the chine bone, and production of the Square Cut Cube by extending the grading and 5/6 scribe cuts through the eye muscle and rib cage. At the commencement of the project, both tasks were performed manually by processing plants and there were no commercially available automated systems capable of carrying them out on beef sides.

Manual chine removal is typically undertaken using a bandsaw, a hand-held powered saw, or by “fleecing” the muscle away from the chine bones with a knife. These approaches expose operators to significant safety and ergonomic risks. Bandsaws and powered saws present the potential for serious laceration and amputation injuries, while knife-based fleecing is physically demanding and creates repetitive strain risk. Manual processing can also result in yield loss where eye muscle is not fully recovered from the cube roll region. Safety bandsaws can reduce some operator risk, but they do not eliminate the hazard, do not necessarily protect nearby personnel, and provide no assistance in accurately guiding the cut.

The Square Cut Cube operation presents a different but related challenge. Although the existing IR-SCRIBE system can automatically place the relevant scribe cuts through the chine, operators must still manually extend those cuts through the muscle and into the rib cage. Variability in the manual knife path can produce uneven or non-parallel faces on the cube roll and striploin, requiring additional trimming and reducing recovery from some of the most valuable primals on the carcase. The project therefore sought to determine whether robotic systems could perform these tasks more consistently while improving worker safety, reducing reliance on manual labour, and protecting or increasing product yield.

The research built on the successful development and production implementation of the IR-SCRIBE robotic beef scribing system at Kilcoy Global Foods under AMPC project 2022-1185. IR-SCRIBE demonstrated that AI-driven robotics could identify anatomical features and perform four beef-side scribing cuts without requiring more complex sensing technologies such as X-ray. Intelligent Robotics and Kilcoy Global Foods subsequently completed a self-funded feasibility investigation into chine removal and Square Cut Cube production. That work established that the proposed tasks appeared technically feasible, enabled initial tooling and stabilisation concepts to be tested, and allowed suitable robots and supporting equipment to be identified.

The main research question was therefore not simply whether the tasks could be automated, but how robotic chine removal and Square Cut Cube operations should be performed to provide sufficient confidence for progression to a production implementation. The project examined the required tooling, robot capability, carcase stabilisation, camera arrangement, vision processing, calibration, cut-path definition, sequencing and cycle performance. Its intended outcome was the demonstration of both operations on stationary beef sides using semi-automated vision processing, with the trials designed to reproduce the critical technical elements of future production operation.

The primary target audience for the research was the Australian red meat processing sector, particularly beef processors seeking to improve yield, workplace health and safety, labour utilisation and production efficiency. Kilcoy Global Foods acted as the principal processing partner for the project. The results were intended to inform whether and how the two modules should proceed to production development.

Specifically, the project outcomes were to be used to update the production concepts, define the required equipment and technical approach, refine value-proposition estimates, and prepare scopes and costings for subsequent prototype and production projects. Success was to be assessed through demonstration of the chine removal and square cut cube roll automation concept, collection of sufficient design data for the next development stage, and progression toward systems capable of operating under full production conditions.

4.0 Project objectives

Chine Removal Chuck and Cube Roll (Module #2)

1. Demonstrate cycle of removing chine from chuck and cube roll portion of a stationary beef side to verify tooling, robotic, vision processing/camera and stabilisation requirements.
2. Update the production concept with learnings from the trials, and outline scope and costing for a production project.

Square Cut Cube (Module #3)

1. Demonstrate cycle of cuts on a stationary beef side to verify tooling, robotic, vision processing/camera and stabilisation requirements.
2. Update the production concept with learnings from the trials, and outline scope and costing for a production project.

5.0 Methodology

1. Review of KGF and IR Feasibility project outcomes, and Project Plan for current project (including Go/No Go/Redirect gate).

2. Procuring Long-Lead Equipment:
   a. Testing area evaluation, high-level layout of testing setup, specification of testing area requirements.
   b. Analysis of Feasibility project outcomes for robot requirements make, model, reach, payload, controller specifications including required options. Assessment of next gen controller functionality differences and changes to requirements specification.
   c. Develop concept simulation for confirmation of robot selection.
   d. Procure robotic arm and robot controller (including required options).

3. Trial Area Equipment Design and Procurement (Chine Removal and Square Cut Cube Testing):
   a. Mechanical and electrical design and detailed design of remaining trial items, including the following:

      i. Stabilisation mechanism common to square cut cube and chine trials to stabilise beef sides. Must incorporate design elements for requirements of each task.
      ii. Robot base suitable for the testing area as well as reach requirements for both chine removal and performing both square cut cube cuts.
      iii. Specific Chine removal required items modifications to chine removal tool and controls, chine removal trial blades, rollface adapter, camera with lighting as per camera and FOV requirements and performing controlled clean of the area.
      iv. Trial electrical panel.
      v. Any required stabilisation / platforms for performing manual pre-cuts.
   b. Further simulations, and test area layouts to finalise designs.
   c. Detailed design drawings/schematics and procurement of manufactured items.
   d. Initial programming for robot and vision for performing trial routines, calibration, communications, controlling hardware.
4. Robotic Testing and Trial area install and setup.
   a. Workshop trialling of Initial robot programming and transition to next-gen controller.
   b. Design and procure prototype chine removal tool.
   c. Install into testing area: Robot mounted to robot base, stabilisation assembly, manual scribe cutting area, cameras, electrical panel.
   d. Update simulations / production concept brief with learnings from trials
   e. Finalise initial programming for robot and vision for performing trials.
   f. Perform initial site assessments of cut specifications and boning room impact
5. Chine Removal and Square Cut - Stage 1 - Tooling Validation.
   a. Initial Square Cut trials to Validate tool concept.
   b. Initial Chine Removal Trials to validate tool concept.
   c. Mount chine removal tool to robot, perform calibration procedures.
   d. Perform series of trials assessing:
      i. Ability to perform target chine removal cuts.
      ii. Stability.
6. Chine Removal and Square Cut - Stage 2 - Further Development.
   a. Continue square cut and chine removal development trials.
   b. Sequencing of tasks to perform cuts; assessing and trialling ideal start conditions.
   c. Incorporation of sensing; cut path identification.
   d. Cycle time analysis and improvement.
   e. Tooling considerations.
   f. Refine stabilisation requirements.
   g. Refine camera positioning requirements and calibrations.

7. Chine Removal and Square Cut - Stage 3 Optimisation.
    a. Continue square cut and chine removal development trials further integrating vision with robot operations, tooling and stabilisation optimisation and cycle time optimisation.
8. KGF supply of support labour, product for trials and preparation of trialling area:
    a. a. Kilcoy retrofit carcass chillers (2) to comply with export standards to be able to conduct trials. One to chill the carcass the chiller next door to setup robots.
    b. Kilcoy supply Carcasses to the trial area over full trial period.
    c. Kilcoy Expert personnel to manage trials onsite and provide process support on key deliverables.
    d. Operating costs of the room- refrigeration/power/water and consumables.
9. Chine Removal and Square Cut Demonstration
    a. Demonstration to AMPC and KGF of semi-auto cutting cycle to prove concept.
    b. Next stage development, commercialisation, extensions, and adoption discussion with AMPC and meeting minutes submitted to AMPC.
10. Final Report:
    a. Report outlining summary of findings.
    b. Update production concept for each module.
    c. Potential costing for production project(s) as next stage.

6.0 Discussion

6.1 Review of Feasibility Learnings and Project Plan

6.1.1 Kick-off Meeting Recap Notes

- **Project Kick-off and Roles Clarification:** IR and KGF team members introduced themselves and clarified their roles and responsibilities for the AMPC project, establishing main contacts for reporting and outlining the collaborative approach between Intelligent Robotics (IR) and Kilcoy Global Foods (KGF).

- **Project Scope, Objectives, and Milestone Structure:** IR team members detailed the AMPC project's scope, focusing on testing chine removal and square cube cutting methodologies using robotics, and outlined the milestone structure, timelines, and expected deliverables, with input from Kilcoy team members.

    - **Project Objectives:** The project aims to test and validate robotic methods for chine removal and cube cutting, with the goal of preparing for a future production-ready system.

    - **Clarification on Testing vs. Production:** IR clarified that this project is strictly for testing in a trial room, not for immediate production line deployment. The outcome will inform whether and how to proceed with full-scale implementation.

- **Technical Discussion on Cutting Methodologies and Yield Optimisation:** IR and Kilcoy team members discussed technical considerations for chine and cube cuts, including yield analysis, qualification criteria, and the need for iterative testing and site visits to refine cutting strategies and maximise value.
- **Trial Room Location and Facility Constraints:** IR and Kilcoy team members evaluated potential locations for the trial room and considering alternative spaces.
- **Next Steps and Scheduling:** IR and Kilcoy team members coordinated next steps, including sharing layout drawings, scheduling a site visit and assigning follow-up actions for facility analysis.
- **Review of Previous Feasibility Work:** IR team members summarised prior feasibility studies and trials conducted with KGF, including manual and robotic chine removal and cube cutting tests, to inform the current project's approach and highlight lessons learned.

6.2 Procuring Long-lead Equipment

Testing area footprint evaluation, high-level layout of testing setup, specification of testing area requirements

A number of candidate areas have been identified with an available footprint limitation of ~7.5 x 5.3m for the trialling area, and rail height between 3.6m and 4.5m.

The following services will need to be provided to the area:

- 3 phase power (for the robot controller and electrical panel powering tooling, cameras etc)
- Single phase power (for trialling PC and laptops)
- Dry air (for pneumatic components)
- Air conditioning (for maintaining product temperature)

A layout was created which could cater to these requirements and to take advantage of the overhead rails above to handle both trial scenarios, to remove the cost and time required to re-install the robot between trial versions.

Analysis of Feasibility project outcomes for robot requirements

It was decided that a Staubli robot should be used for the testing as these would be the preferred robots for the final production system given their ability to operate in the meat processing environment. From the concept simulation created, it was determined that the TX2-200L model be selected based on its reach. The required controller software additions were also assessed, including features available in the latest generation of controller.

Develop concept simulation for confirmation of robot selection

Simulations were performed and mapped out for both the Chine Removal and the Square Cut Cube Roll robot processes. This was performed to ensure that the robot selection was adequate for both tasks. This simulation was done on dimensions determined through the trial room layout that was developed previously.

Through the development of these two simulations, the robot reach, payload and functionality was verified in order to further confirm the selected robot.

Procure robotic arm and robot controller (including required options)

Once all simulations, layouts and Robot Specifications were complete, the procurement process began. This included purchasing the robot, controller, and associate cables required to connect the modules.

Procure other long-lead time items (mechanical components)

In order to meet the timelines for the trials, the supplier for the long-lead time mechanical components needed to be locked in. The main items for this supply include the backing system, and the robot base, as well as end-of-arm tooling and fixtures.

The scope of the project was discussed with the supplier, together with the simulations developed, process requirements, and target timeframes. The supplier was to provide mechanical design assistance, drafting and manufacture services for the associated items. The scope was able to be defined and an order placed for these items.

Backing Support

The backing support is envisioned to be adaptable between both the chine removal and the square cut tasks. It will be designed in a fashion to allow the testing of different stabilisation arrangements. The backing support will also possess movement to allow beef sides to be easily positioned and removed from in front of the robot.

Robot Base

The robot base will be designed for the bottom-cable-entry configuration of the robot, at the appropriate height for the trialling area rails and relative to the backing support. Load distribution will also be taken into consideration relative to the slab specifications of the trialling area.

End-of-arm tooling and fixtures

For chine removal, end-of-arm mounting for the chine removal tool will be provided, as well as any guidance required for cabling. For the square cut, the tool itself will be designed and manufactured, as well as the end-of-arm mounting. The tooling will be designed as per the design specifications discovered during the Feasibility project.

6.3 Trial Area Equipment Design and Procurement Chine Removal and Square Cut Cube.

6.3.1 Variation

During the designing and planning performed in this milestone, an opportunity arose to re-assess how best to execute the remainder of the project to best achieve its target goals. There were also a number of events which arose which factored into this thinking:

1. *Ideal target install date for large equipment is during shutdown*

The trial area allocated is a marshalling chiller which will be allocated to the project for its duration. In order to minimise disruption to Kilcoy's operations, the project timeline was altered to accommodate installation during a shutdown period.

2. *Pivot to trialling Square Cut with alternative tooling and more advanced controls*

With the upgraded communications and motion functionality of the latest generation of Staubli controller, an opportunity arose to use more complex "smarts" to perform the square cut using a simpler design than originally envisioned. This would have significant benefits in terms of using a smaller robot and less footprint required. The original concept would still be a contingency.

3. *Pivot to trialling Chine Removal alternative tooling*

During this milestone, the idea of an alternative chine removal tool was also explored. The new concept possessed lower risk regarding stabilisation and cycle time, as well as greater flexibility for cutting paths. The original design would remain as a contingency if these initial prototype trials are unsuccessful.

4. Modification of trial sequence to accommodate learnings

The current milestone structure focused on investigating chine removal and the square cut cube roll sequentially. Intelligent Robotics proposed alternating trials for each application to enable work to continue while learnings are adopted from the previous trial, particularly in the case where re-work or new prototypes are required based on the trial learnings.

New Proposed Milestone Methodology:

<u>MS 4 - Robotic Testing and Trial area install and setup</u>

<u>MS 5 - Chine Removal and Square Cut - Stage 1 - Tooling Validation</u>

<u>MS 6 - Chine Removal and Square Cut - Stage 2 - Further Development</u>

<u>MS 7 - Chine Removal and Square Cut - Stage 3 - Optimisation</u>

<u>MS8 – Kilcoy supply of support labour, product for trials and preparation of trialling area - *unchanged*</u>

<u>MS 9 - Chine Removal and Square Cut Demonstration</u>

<u>MS10 – Final Report</u>

6.3.2 Equipment Design

Robot Base Design

The slab ratings for the trial chiller were specified as 4kPa for area load or 10kN for point load. The slab construction comprises a wear slab, insulation, a waterproof membrane, and a load slab. To reduce structural risk, and also to prevent needing to interfere with the waterproofing, the robot base was designed for mounting directly onto the beams that support the chiller's rail structure. During the design process, finite element analyses (FEA) was conducted to verify the load distribution through these beams. The analysis confirmed that the resulting loading was significantly less than that of a chiller fully loaded with beef sides. The robot base is currently being manufactured, with delivery scheduled prior to the targeted installation during the Christmas shutdown.

The design created could be used in future applications to allow robots to be used in areas where the slab rating is insufficient to mount them to the floor.

Stabilisation Design

The stabilisation mechanism to be utilised during both the chine removal and square cut trials was designed to serve common requirements across these tasks.

Key features of the mechanism include the ability to reposition as needed, attach additional components when required, and adjust the level of engagement with the carcase. These flexible design aspects allow customisation of the support provided, ensuring that it is tailored to the specific needs of each trial scenario.

The same stabilisation arrangement will be adopted for initial trials of the square cut application, allowing for comparative assessment and optimisation. The trial process will help determine the most effective stabilisation approach, which will also be influenced by the choice of tooling used during the trials.

Sensing Equipment

Several sensing requirements were identified for trialling. During the design phase, simulation work was conducted to determine optimal camera positioning and mounting requirements.

Based on the design and simulation results, the appropriate cameras were specified and procured.

Trial electrical panel and safety

Once the sensing layout was planned and the high-level trials were identified, a Safety Risk Assessment was performed to ensure the safety of all personnel involved, and that the controls system was designed as such.

			Assessment of the Risk without control measures																	
				Risk Index RI					Safety Related Parts of a Control System SRP / CS			Assessment of the Risk with control measures	Risk Index RI					Safety Related Parts of a Control System SRP / CS		
Ref.	Activity	Hazard Description	Identify the Risk	Severity S (S2 Worst)	Frequency F (F2 Worst)	Avoidance P (P2 Worst)	Occurance O (O3 Worst)	Risk Index RI	Required Y/N ?	A S4024.1501 Control Category	A S4024.1503 Performance Level PLr	Safety Measures	Severity S (S2 Worst)	Frequency F (F2 Worst)	Avoidance P (P2 Worst)	Occurance O (O3 Worst)	Risk Index RI	A S4024.1501 Control Category	A S4024.1503 Performance Level PLr	Further Risk Reduction Required?
CR07	Operation Maintenance Cleaning	Slips, falls	Operators/maintenance/Intelligent Robotics personell walking inside the Trial area fall over hosing, wiring pipes on the floor, or slip due to wet surfaces	S1	F2	P1	O2	1	N	--	--	Use of a high-friction floor to help prevent slips. Walkovers used over piping whenever possible. Doors to work area locked while IR personnel are not onsite and in the work area. Locks work from the outside, to stop non IR personnel from entering area when IR personnel are not onsite.	S2	F1	P1	O2	2	--	--	No
CR08	Maintenance/Operation	Dazing	Vision lighting dazes IR personnel while inside Trial area.	S1	F1	P1	O2	1	Y	Cat 1 or 2	PLa	Control system used to shut off lighting when required for work inside the Trial area. Lighting defaults to off.	S1	F1	P1	O1	1	Cat 1 or 2	PLa	No
CR09	Maintenance	Falling	Maintenance worker maintaining equipment up high falls. (Conveyors, cylinders, etc)	S2	F1	P2	O2	3	N	--	--	Correct platform working at heights equipment required to be used to get to high places, along with normal plant procedure.	S2	F1	P1	O2	2	--	--	No
CR10	Operation Maintenance	Noise	High level of noise due to various motors, conveyors and robots within the area.	S1	F2	P2	O3	2	N	--	--	Hearing protection in accordance with plant guidelines to be utilized.	S1	F2	P1	O1	1	--	--	No
CR11	Operation Maintenance	Crushing, shearing	IR personell walk into Trial area at carcass exit/entry positions and get cut by spinning saw blade	S2	F1	P2	O2	3	Y	Cat 2 or 3	PLd	Dual safety contactors with feedback used to power saw motors, or STOs where applicable. Distributed Estops around the Trial area. Safety power lockoff with clasp for locking out automatic safety to the Trial area. Lockout location is outside of Trial area, away from Trial area to ensure all lock out locations are far away from Trial area. Physical chain guards around Trial area to stop entry during operation. IR personnel only inside chiller during operation. Robot to be run in manual first wherever possible for programming testing. Robot to	S1	F1	P1	O1	1	Cat 1 or 2	PLa	No

Figure 1 - Portion of Safety Risk Assessment

Once the SRA was reviewed, the electrical system architecture was developed, and panel layouts determined so that all components could be ordered to begin the panel build. Major components of design included:

- Splitting up of ELV and LV power into different panels for safety
- Protection of devices from water ingress
- Designing plugs to allow for easy changing of Low Voltage tooling without the need for licensed electricians

Simulations and Layouts

Throughout this milestone, a comprehensive series of simulations and layout assessments were carried out. These activities were essential to ensure that the robot's reach capabilities were sufficient for the intended range of test cases. By thoroughly evaluating the robot's operational envelope, the team confirmed that it could accommodate various testing scenarios. They also defined the required robot positioning in space which fed into the robot base design, as well as the stabilisation design.

During the design of the trials, as well as the mechanical and electrical components, the system was deliberately constructed with significant adjustability. This approach provided the flexibility to adapt and modify the trials as new insights were gained, allowing for different testing methods to be implemented as required.

Simulations were executed for each operation and for every tool being developed for testing. These simulations played a critical role in informing the mechanical design, ensuring that the robot possessed the necessary area and reach to effectively perform each individual trial.

Initial Programming for robot and vision

To mitigate the risks associated with implementing new technologies, targeted programming efforts were undertaken prior to the trials.

In addition to the communications programming, it was necessary to construct an application layer to support integration with the vision system. This application layer forms the core structure that enables communications to be linked directly to the vision system, ensuring that communication replies can include data generated by the vision system.

It was also necessary to develop a pass-through communications platform to facilitate seamless interaction between the Vision PC and the robot. To achieve this, a Powerlink Master was implemented to manage the fieldbus operations. The B&R PLC was selected for this role, and a dedicated project was initiated to develop and deploy code that enabled efficient pass-through communications between both devices, ensuring reliable data exchange throughout the system.

Additionally, a Staubli Robot Program was developed.

Chine Removal Tooling

The custom prototype chine removal tool was developed using simulation results and 3D carcase side data to guide the design process. The tool components were carefully sized and selected, using the previous prototype tool as a reference point to match anticipated target speeds and torque requirements. These components were ordered in advance due to their extended lead times.

Installation Planning

The transport of large items into the trial chiller during the Christmas shutdown is a critical, near-term objective for the project. Multiple equipment transport options were evaluated; however, each alternative required chiller panel modifications to create an opening sufficiently large for equipment entry, as well as the use of cranes for lifting.

Ultimately, the selected transport route utilises a production area entrance through a series of corridors to the trial chiller. The principal constraint along this route is the entrance door, which measures 1100mm in width and 2365mm in height. Measurements confirmed that both the robot and its controller can pass through this opening, and the design of the robot base structure has been tailored to fit within these dimensions.

Another challenge is presented by the two inclined hallways, each with a 5 to 8-degree slope. Due to space limitations, forklift use is not feasible for equipment transport in this area. To address this, a custom dolly and a winch system have been devised to move the equipment up these hallways, with plans to use the same method for retrieval after testing is complete.

Smaller equipment pieces can be transported during production as needed. Nonetheless, the aim is to move as much equipment as possible into the area prior to the Christmas shutdown.

In addition to the planning for the installation, planning was performed around the protection of equipment in a wet area. This included the design, specification and ordering of:

- Conduits for cable protection
- Tubs and enclosures for protection of robot controllers, PCs and other electrical equipment
- Tubs for protection of extended cable lengths to be wrapped up
- Other protection mechanisms to resist chemical washdown

Trialling Area Services

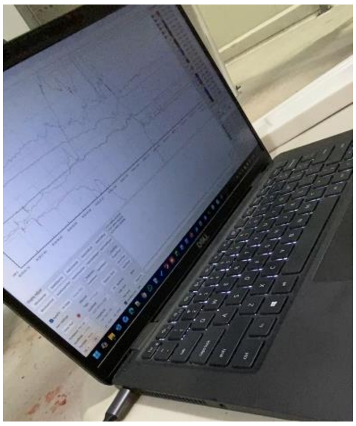
The required services for the trialling area were carefully assessed and details of these requirements were communicated to KGF. To support the equipment within the chiller, KGF will undertake the installation of power and pneumatic outlets.

No additional services were identified as necessary for the area at this stage. For cleaning purposes, there are hot water and cleaning chemical points located conveniently near the chiller, which can be utilised as needed. In addition, a sanitation station is available in close proximity, allowing tools to be sanitised when required.

6.4 Robotic Testing and Trial area install and setup

Square Cut Cube Roll tooling force data acquisition for concept development

A site trial was performed whereby a force-torque sensor was taken to site and attached to a handheld tool prototype. Force and torque data was then captured while the square cut cube cuts were performed across four beef sides. This data and the learnings from the trial were used to understand the starting point for robot cutting paths, and also the amount of force imparted to the side during these moves.



Workshop Trialling

The initial robot programming for the trials was performed. This included programming the:

- Calibration routines for cameras and tools
- Various manual cut path programs for the envisioned first-stage trials
- Integration with camera acquisition and force-torque sensor data acquisition
- State machine development for cycles

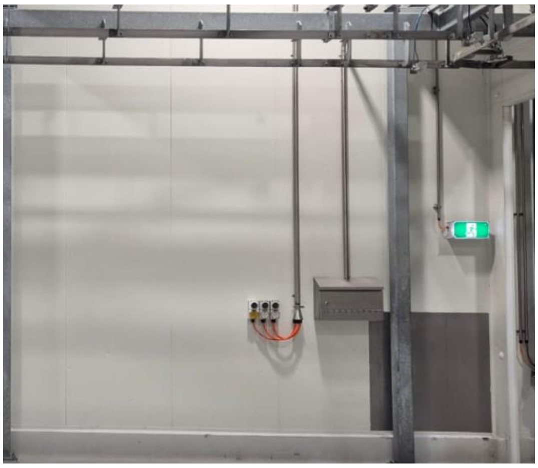
These programs were setup for the new generation CS9 within Staubli Robot Studio and tested via simulation.

Design and Procure Prototype chine tool

The chine removal tool was also concepted and designed. This is a custom tool that needed to meet footprint, power, weight and speed requirements for the task.

Testing area installation

The robot, stabilisation assembly, cameras and electrical panel were all successfully transported into the testing area during the Christmas shutdown as targeted and successfully installed. Kilcoy also prepared the room as discussed, by providing the required power and air services to the location requested. The installation was completed successfully.



Update simulations / production concept and finalise initial programming

In preparation for the trials in milestone 5, and based on the workshop and force-torque sensor trials performed earlier in this milestone, the simulation and production concept were updated and the initial programming for the MS5 trials was finalised.

No major changes were made to the production concept since those outlined in Milestone 3.

The simulations were updated together with the robot program to finalise the codebase in preparation for the trials in milestone 5. Similarly, the base vision programming was performed which included:

- Calibration vision routines
- Camera acquisition
- Force-torque sensor acquisition and storage

- Communications with the robot
- State machines for each of the trial scenarios

6.5 Square Cut Cube Roll – Stage 1 – Tooling Validation

6.5.1 Variation

The project fell behind in this milestone due to additional work that needed to be done to confirm the concept and design of the prototype chine removal tool. While this delayed being able to perform the trials, it was believed that was important in reducing overall risk to the project and enable greater confidence in the prototype's design. IR, KGF and AMPC reforecast the milestones accordingly to balance getting the project back on track while appropriately managing risk.

6.5.2 Square Cut Cube Roll Tooling Validation

Mounting of Force-Torque Sensor and Calibration

Initially, the robot was fitted with a Force/Torque (F/T) sensor to evaluate the usefulness of force data during robotic operations. The objective was to determine whether measurable changes in force and torque could be used while performing the operation automatically.

Figure 2 - Force torque sensor mounted to robot (left) and calibrated robot setup (right)

Trialling of Tool #1

Multiple parameter combinations were trialled, varying:

- Cut path
- Manual speed scaling
- Cut profile

Across the trial set, cutting performance was generally strong. The resulting cut faces were smooth although several limitations were identified:

1. Limited Stroke Length
   Due to the tool's shorter length, its path was less efficient.
2. Residual Fat at Cut Termination
   On some trials, small sections of fat remained uncut at the end of the stroke. This was attributed to the shorter tool length not fully penetrating through the carcase thickness at times.
3. Blade Geometry Advantages
   The tool exhibited greater stiffness and width, which contributed to:
   a. A clean cut face
   b. Greater tool rigidity
   c. Improved stability

Overall, the tool demonstrated feasibility but highlighted limitations in efficiency.

Figure 3 - Images of cuts using the smaller tool

Trialling of longer tool

To evaluate the impact of blade length, a longer tool was designed and trialled.

The longer blade allowed:

- Smoother slicing strokes
- Reduced visible striations on the meat face
- Potential for improved cycle time

However, is also exhibited:

- Reduced stiffness and rigidity
- Slightly less clean cut face under certain conditions

Despite these trade-offs, the longer blade was considered superior in terms of efficiency and overall slicing action.

This led to the decision to design and manufacture a custom tool incorporating both characteristics.

Figure 4 - Images of cuts

Grading Cut Profile Additions for Square Cuts

To produce a square cube roll, it is sometimes necessary to:

- Cut toward the rib bone
- Turn upward within the cut
- Ride along the bone to complete the grading profile

Trials were performed to determine whether the tool could be twisted within an active cut without excessive damage or instability.

Figure 5 - Trial with hitting rib during grading cut and tilting up rib

A method was found which enabled the tool to perform the desired path successfully for this situation.

Force/Torque Data Analysis

Force and torque data were logged throughout all cutting trials. A custom analysis program was developed to visualise:

- Force components
- Torque components
- Robot move IDs
- Tool velocities

It was observed that:

- A clear and repeatable change in force/torque was observed when entering the carcase.
- Oscillations in force corresponded directly to the programmed motion.
- Cutting forces were well within requirements.

This data confirms that:

- The F/T sensor provides usable information during cutting
- Force signatures may be leveraged for collision detection

It was therefore decided to retain the F/T sensor for subsequent development stages.

6.6 Chine Removal – Stage 1 – Tooling Validation and Stage 2 – Further Development

6.6.1 Chine Removal Tooling Validation

Tool Checks

The prototype chine removal tool was mounted and checked before progressing into cutting trials. The purpose of these checks was to confirm that the tool could be operated safely and repeatably on the robot.

The tool must be compact enough to operate within the available space, while still having sufficient stiffness and power to perform the cut successfully. For this reason, the initial checks focused on the following items:

- Tool stability during operation.
- Clearance between the tool, the carcase, and surrounding structures.
- Tool mounting and stiffness at the robot flange.
- Tool centre point definition and repeatability.
- Approach and retract paths for safe robot operation.
- General checks of tool vibration and robot-mounted operation.

Overall, the tool checks provided confidence that the prototype tool could be progressed into initial robot path trials, while also identifying that careful setup and inspection of the blade tracking will be important for repeatable performance.

Initial Cut point teaching for manual cut trials

Following the tool checks, initial cut points were taught manually to allow the robot to perform controlled trial paths. This manual teaching step was used to establish the first practical chine removal paths before relying on vision-guided path generation.

The intent was to confirm that the robot could reach the required cutting region, orient the tool appropriately, and move the tool through the target path successfully.

This initial manual teaching process also provided a practical way to assess the correct starting conditions for the chine removal cut.

The manual cut point teaching was therefore an important intermediate step. It allowed the team to validate robot reach, tool orientation, and initial process sequencing before progressing to the more flexible vision-guided approach developed in Milestone 6b.

Throughout the testing, a number of optimisations to the design were identified. As a result, modifications to the tool were designed and prepared for trialling in the next milestone.

Learnings

The on-site tests conducted during this milestone led to the following key learnings:

- The prototype chine removal tool could be mounted and operated on the robot, with the blade successfully spun up progressively to the target blade speed.
- The concept remains feasible; however some modifications were required.
- The biological variation needs to be accounted for in both the tool design and the generated cut path.
- Manual point teaching was useful for validating robot reach, tool orientation, approach positions, cut start positions, and retract movements before progressing to vision-guided path generation.
- Stabilisation is important for yield control.
- The manual cut trials confirmed the need to move toward a vision-guided process, as fixed manually taught paths are unlikely to be sufficiently robust across varying carcase sizes and presentations.

6.6.2 Chine Removal Further Development

Camera Calibration

Camera calibration was performed to allow the robot-mounted vision system to be used for Chine Removal cut path generation. The purpose of the calibration was to establish the relationship between the camera and the robot flange so that points selected or identified in the image could be transformed into robot coordinates.

For the Chine Removal task, calibration accuracy is particularly important because the tool path must be positioned relative to specific anatomical features.

The calibrated camera setup was then used for initial vision-guided trialling, where selected points in the image were used to define the chine removal path.

Initial Vision Guided Cut Trialling

Initial vision-guided Chine Removal trials were performed using image data captured from the carcase. The objective was to move away from purely manual point teaching and toward a process where the required tool path could be generated from carcase-specific image data.

In the initial process, the operator selected key points in the image to define the relevant points of interest and calculate the desired cutting path. The robot path was then reviewed before being used to guide the tool through the intended chine removal cut.

This approach allows the chine removal path to be adapted to each carcase rather than relying on a fixed path. This is important because the size, orientation and presentation of the carcase can vary, and the chine removal path must remain aligned to the anatomical features rather than to a fixed robot coordinate frame.

The initial vision-guided trials confirmed the value of using carcase image data to define the cut path. However, the trials also showed that a simple path definition was not always sufficient to describe the required cut. Therefore, code was developed during the trailing period to add additional control points to the path.

Extended Cut Path definition during trialling

During the vision-guided trials, several enhancements to the cut path definition were introduced to improve the reliability and usability of the generated path. These enhancements were aimed at making the robot path more practical for the physical tool, as well as better defining the cut to remove the required chine.

Figure 6- Removed chine with updated cut definition

Stabilisation

Various geometries of the stabilisation assembly were trialled to understand the ideal side presentation and stabilisation through the chine removal process.

6.7 Square Cut Cube Roll – Stage 2 – Further Development and Stage 3 – Optimisation

6.7.1 Square Cut Cube Roll Further Development

Camera Calibration

The camera was mounted at an offset distance to the robot flange, and a calibration board placed on a tripod stand was used to assist in the camera calibration process. During the calibration, the robot moved to a number of positions around the calibration board. This information was then used to calculate the position of the camera relative to the robot flange. Figure 7 shows the camera mounted on the robot, as well as the calibration board used.

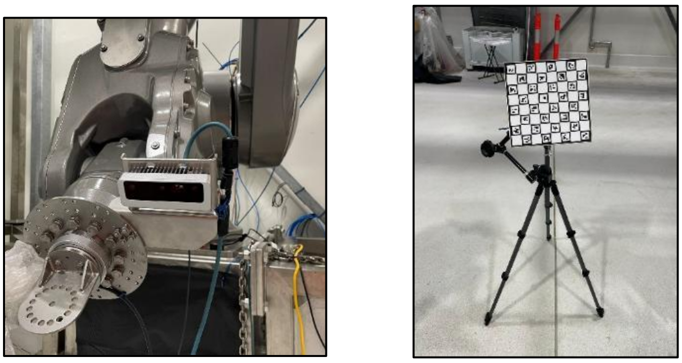


Figure 7- Camera position on the robot flange (left) and Calibration board (right)

To validate the calibration, a touch test was performed, where the robot would trigger an image capture, and an operator would click on a position in the image. The robot would then move a pointer tool to the clicked position. Figure 8 shows an example of the touch test, with the clicked position shown in the left image and the position the robot moved to shown in the right image (the pointer tool in the right image is attached to the robot).

Figure 8- Calibration Touch Test - Clicked Point (left) and Point touched by robot (right)

Vision-Guided Cut Path Generation

With the camera calibrated and validated, the next step was to calculate the ideal cut path based on the 2D and 3D image data captured by the stereo camera. In this process, the robot captures an image of the beef carcass. The operator then clicks on multiple features of interest. The required cut path for that side is then generated.

Examples of vision guided cuts are shown in Figure 9. The left image shows a five-six cut, and the right image shows a grading cut.

Figure 9- Vision guided cuts - Five-six cut (left), and Grading cut (right)

Some of the carcasses where the robot performed the vision-guided cutting were tracked up to the boning room. This allowed the Kilcoy staff to assess the yield of the cube rolls. Examples of cube rolls where the robot performed the Square Cut Cube Roll cuts is shown in Figure 10.

Figure 10- Cube rolls where Square Cut Cube Roll cuts were performed by the robot (Front View and Side View)

There was positive feedback from the Kilcoy staff upon examining the cut quality of both the five-six cut and the grading cut, with some recommendations from them around cut quality optimisations. These recommendations were implemented and tested in Milestone 7a.

Cycle Time Analysis

To ensure that the proposed system can handle the infeed rates at Kilcoy, the Square Cut Cube Roll process was performed with the robot running in automatic mode. The time taken to perform each step of the robot sequence was profiled. The robot moves occur after the vision program sends the cut path to the robot. The actual cut path generation time is negligible compared to the robot movements.

Further optimisations in the robot moves were carried out in Milestone 7a.

Learnings

The on-site tests conducted during this milestone led to the following key learnings:

- The negative impact of tooling which was too short in length was noted.
- Cut quality improved as the robot cutting speed increased.
- Camera calibration optimisations were applied to improve the accuracy of the estimated camera position on the robot, as confirmed by the touch test.

6.7.2 Square Cut Cube Roll Optimisation

New Camera Position

Based on the learnings from the previous milestone, the camera was repositioned. The camera was also changed to an IP67 version, as the previous camera lenses were fogging up from condensation.

Testing the custom tooling

The tooling design was modified based on the learnings from the previous milestone. The new design was able to fully open up all carcasses for both Square Cut Cube Roll cuts. The cut quality of using the custom tool was satisfactory to the Kilcoy staff.

Figure 11- Examples of cuts performed using the custom tool

Carcass Stabilisation

A new assembly was trialled during the Milestone 7a site visit. The new assembly allowed the height of the pushout bar to be adjusted more easily. Over the course of the trials, the various geometries of the stabilisation assembly were trialled to understand the ideal setup.

Another learning from these trials was that the path of the tool during the cut has a significant impact on the stabilisation of the carcass. This was also optimised throughout the trials.

Tool Sharpness Tests

A sharpness tester was used to measure the sharpness of the tool over two days of performing cuts. The sharpness tester was placed in a fixed position, and a robot program was developed to move the robot to a position 20mm above the tester. The operator would then jog the robot down, breaking the sharpness test string, thereby recording the sharpness value. Figure 12 shows this setup. This was used to monitor sharpness throughout trialling, and assess its impact.

Figure 12- Sharpness tester setup

6.8 Chine Removal – Stage 3 – Optimisation

6.8.1 Vision-guided Cut Path Refinement

Findings from previous trials and modifications

In earlier automated chine-removal trials, the cut path generated from the operator-selected points did not adequately account for variation in chine and vertebra size. The specific issues were analysed and the code was improved across a number of areas to address these shortcomings.

Results after updated cut definition

After implementing the updated cut definition, the automated chine-removal system produced more consistent cuts across sides with different sizes and shapes. The adaptive geometry allowed the tool to move in response to the size and dressing variations.

The resulting cuts showed improved preservation of the cube roll compared with the earlier approach. In particular, the updated method reduced the tendency to cut too deeply on smaller sides. At the same time, the adaptive scaling helped maintain sufficient bone removal on larger sides.

The tool collision check also improved the reliability of the cut. This ensured that the tool did not push against the side during cutting.

Figure 13 shows examples of cube rolls after chine removal using the updated cut definition. These examples demonstrate that the revised path-generation method was able to produce clean cuts while maintaining good cube roll retention.

These changes shift the system from a fixed, tuned path to an adaptive path-generation method. The updated method responds to anatomical and dressing variation between sides, while prioritising cube roll preservation.

Figure 13- Examples of cube rolls after automated chine removal using the updated cut definition.

6.8.2 Robot Motion, Cut Speed and Cycle Time Optimisation

Robot motion and cut speed parameters were reviewed during the Milestone 7b trials to balance cut quality, carcase stability and overall cycle time. The objective was to identify a cutting speed that allowed the tool to clear material effectively while minimising disturbance to the carcase during the chine removal cut.

Several cut speed behaviours were observed during the trials. When the robot moved too slowly during the cut, fat burning was observed as the tool remained in contact with the same region for too long. When the robot moved too quickly, the force applied by the robot and tool caused greater carcase disturbance during cutting. The selected robot speed therefore represented a balance between maintaining an acceptable cut, avoiding fat burning, and limiting movement of the carcase.

Robot motions away from the carcase, including approach, retract and return movements, can be further optimised in later development. These non-cutting movements do not currently present as a major cycle time risk.

6.8.3 Medium-Volume Trial and Preparation for Yield Trial

A medium-volume trial was completed during Milestone 7b to assess the chine removal process across a larger number of carcases than the earlier development trials. In total, 30 sides were cut using the vision-guided chine removal process over one day. The purpose of this trial was to confirm that the selected cut path model, tooling arrangement and robot cutting parameters could be applied consistently across multiple sides.

For this trial, the cut parameters were held constant across the 30 carcases. This was important because earlier development work had involved frequent adjustment of cut path settings and robot motion parameters. By holding the parameters constant, the trial provided a better indication of how repeatable the process was under a more stable operating condition.

The medium-volume trial also provided an opportunity to observe practical process requirements over repeated cutting cycles. The trial therefore provided useful preparation for a higher-volume yield-focused trial.

The next planned trial will involve a larger batch of 50 sides. The objective of this higher-volume trial will be to provide a more representative assessment of repeatability, cut quality and yield performance. The carcases will be kept in the chiller after cutting and then sent to the boning room as a batch, allowing yield analysis to be performed on a subset of the trial group.

This approach will allow the chine removal process to be assessed more directly against production outcomes.

6.8.4 Key Learnings

The following key learnings were realised during this milestone:

- Modelling the cut path using additional features improved the ability to scale the tool path to each carcase.
- Tool collision detection improved path robustness.
- Robot cut speed required a balance between cut quality and carcase disturbance. Moving too slowly caused fat burning, while moving too quickly increased carcase movement.

- The medium-volume trial showed that the selected cut path model, tooling and robot cutting parameters could be applied across multiple carcases without changing cut parameters.

6.9 KGF supply of support labour, product for trials and preparation of trialling area

6.9.1 Methodology

Trial Area Preparation – Marshalling Chiller Fit-Out

Following a site assessment conducted at project start (October 2025), the marshalling chiller was selected as the preferred trial location given its available footprint, rail height, and proximity to the existing boning operations.

KGF undertook the following works to prepare the marshalling chiller for trial operations:

- Arrange temporary isolation for the trial area from normal marshalling operations and provide a safety exclusion zone around the robotic equipment.
- Structural assessment of the chiller floor slab and installation of steel load-distribution plates to support the robot base frame loads.
- Assessment and confirmation of structural ceiling and rail integrity for safe hanging of carcasses.

Electrical Installation & Services Provision

KGF's licensed electricians and maintenance personnel installed and commissioned all electrical and utility services required to operate the robotic trial system. This included:

- Running 3-phase power from the main distribution board to the trial electrical panel supplied by IR, including appropriate isolation and circuit protection.
- Installation of single-phase power outlets for the trial PC, laptops, and ancillary equipment.
- Connection of dry compressed air reticulation to the trial area for pneumatic components.
- Ensuring the existing refrigeration plant serving the marshalling chiller was maintained in operation throughout the trial period.

This work was completed prior to commissioning commencement (23 December 2025) and was maintained in a serviceable state throughout the trial period.

Container Arrival & Equipment Marshalling

The robotic equipment was delivered to site via shipping container, arriving on 18 December 2025. KGF coordinated and provided the following support for the container receipt and equipment transfer:

- Coordination of container access and site logistics on arrival.
- Provision of forklift and licensed operator to unload equipment from the container.
- Transport of all robotic equipment from the container reception area to the marshalling chiller trial zone.

- Assisted IR team with positioning of heavy items including the robot base, robot arm packaging, and stabilisation frame components.

Robot Base Frame Installation Support

KGF maintenance and engineering personnel provided direct physical assistance to IR during the installation and commissioning of the robotic test rig. Specific activities included:

- Assisting with positioning and alignment of the robot base frame on the prepared floor slab.
- Provision and operation of tools and rigging equipment for bolting down the robot base.
- Assisting with assembly of the stabilisation frame and structural anchorage.
- Forklift support for raising and placing the robot arm onto the base during initial installation.

Christmas Shutdown Commissioning Support

The IR team commenced commissioning activities from 23 December 2025 through to 8 January 2026. Although KGF's facility was in a reduced Christmas/New Year shutdown operating state, KGF provided dedicated personnel to support the IR commissioning team. This included:

- Maintenance staff attendance to assist with any facility, power, or services issues arising during commissioning.
- Site access coordination and safety management during the shutdown period.
- Provision of environmental conditions (refrigeration operation) in the trial chiller throughout the shutdown and commissioning period.

Ongoing Operational Support During Trials

From 12 January 2026 onwards, KGF commenced active on-site trial support. KGF expert personnel provided the following support across the full trial period:

- Pre-operational hygiene checks: KGF food safety and hygiene team conducted pre-operational inspections of the trial chiller prior to each trial day to ensure that trailed beef sides and all equipment maintained KGF's export food hygiene standards.
- Side delivery and staging: KGF staff collected specified beef sides from the main processing floor or boning room and transported them to the trial area in accordance with trial schedules provided by IR.
- Process expertise: KGF boning room supervisors and process technicians attended trials to provide expertise on cut specifications, bone structure, and quality assessment of trial outputs.
- Boning room assessment: KGF staff assessed cube rolls and boned product produced from trial sides through the boning chain, collecting feedback from boners and providing yield and quality data.
- In-boning room trials with chine removal and bone marking: KGF coordinated the movement of trial bodies into boning room operations to pre-test the chine removal cut impact on downstream boning.
- Removal trial product: KGF arranged the removal of all product post-trialling and conducted boning analysis to review effectiveness of trials.

6.9.2 Product Supply for Trials

KGF supplied beef sides and boned product to the trial area over the full trial period.

KGF staff managed all aspects of product logistics within the site, including delivery of suitable sides to the trial chiller and removal of product post-trial.

6.9.3 Support Activity Schedule

The following table summarises the status of all KGF activities under Milestone 8:

Activity	Status	Period / Notes
Marshalling chiller fit-out and structural works	Complete	Prior to Dec 2025
Electrical installation and services commissioning	Complete	December 2025
Container arrival and equipment marshalling	Complete	18 December 2025
Robot base frame installation support	Complete	Dec 2025 – Jan 2026
Christmas shutdown commissioning support	Complete	23 Dec 2025 – 8 Jan 2026
Ongoing operational and labour support for trials	Complete	12 Jan 2026 – May 2026
Product supply	Complete	Across full trial period
Pre-operational hygiene checks	Complete	Each trial day throughout

All activities under this milestone have been completed. There were no significant issues encountered that impacted the delivery of the trial program.

6.9.4 Discussion

KGF's contribution under this milestone was essential to enabling the execution of the robotic chine removal and square cut cube trials at the Kilcoy facility. The selection and preparation of the marshalling chiller as the trial area provided IR with a food-safe, controlled environment that met all necessary export hygiene requirements and provided sufficient space and services to operate the robotic test rig effectively.

The structural and electrical works undertaken by KGF ensured that IR's equipment could be safely installed and operated. The provision of power, compressed air, and refrigeration throughout the trial period removed operational barriers that would otherwise have required significant additional cost or time investment by IR.

The direct participation of KGF boning room staff, supervisors, and process technicians in the trial program added significant value to the project outcomes. KGF's personnel contributed practical process knowledge, enabling IR to refine cut specifications and assess yield impacts in real time. Feedback from KGF's boning team was instrumental in informing the optimisation of cut paths and tooling across Milestones 5 through 7.

The supply of product across the trial period provided IR with a consistent and representative sample of Kilcoy's production output, enabling meaningful trial data to be generated and analysed. The inclusion of both killed sides and boned product allowed the downstream yield impacts of the robotic cuts to be assessed in the boning room, which is a critical input to the final production concept costing.

KGF's pre-operational hygiene checks ensured that the trial area and all product handled within it maintained compliance with KGF's export food safety requirements throughout the project, which was a key requirement for the trial to operate within KGF's live production facility.

6.10 Chine Removal and Square Cut Cube Roll Demonstration, Next steps

6.10.1 Demonstration Methodology

The Chine Removal pre-work included:

- Checking the chine removal tool calibration.
- Confirming calibration accuracy prior to cutting.
- Performing a test run on 10 sides to assess cut results and tune parameters before the high-volume trial and demonstration.

The high-volume Chine Removal trial involved performing robot cuts on up to 50 right-hand carcases.

A yield analysis was performed by KGF based on the carcases cut during the high-volume trial. The analysis included:

- Retaining 10 corresponding left-hand sides from the trial group as controls.
- Sending the left-hand control sides to the boning room first, allowing the boning room team to remove the cube roll using their normal method.
- Using the first 40 robot-cut right-hand sides to allow the boning room team to become familiar with the new cube roll removal process.
- Comparing the final 10 robot-cut right-hand sides against the 10 left-hand control sides.
- Using the comparison to assess yield outcomes and determine whether robotic chine removal reduced cube roll loss while still achieving the required chine removal result.

After completion of the Chine Removal trial and demonstration, the Square Cut pre-work and demonstration were performed. The pre-work steps included:

- Changing over from the chine removal tooling to the square cut cube roll tooling.

- Performing camera and tooling calibration.
- Performing initial manual and automatic cuts on a small number of sides to tune cut parameters.

The Square Cut demonstration involved performing both cuts on 7 right-hand carcases.

6.10.2 Chine Removal Calibration Check

A calibration check was completed before the high-volume Chine Removal trial and demonstration to confirm that the robot-mounted vision system was still accurately aligned to the robot.

To further prepare for the high-volume trial and verify the calibration under cutting conditions, 10 chines were removed from right-hand sides before the main trial. The resulting cut positions were reviewed and were found to validate the calibration results. Figure 14 shows the results of one of the cut sides. As shown in the images, the chine was removed with minimal cube roll loss. This provided confidence that the calibrated vision system and tool path generation process were suitable for the high-volume Chine Removal trial and demonstration.

Figure 14- Chine removal after calibration

6.10.3 Chine Removal High-Volume Trial and Demonstration

The high-volume Chine Removal trial was completed to assess the repeatability of the vision-guided chine removal process across a larger number of carcases and to provide a basis for yield comparison. The trial involved robotic chine removal on right-hand sides, with corresponding left-hand sides retained for comparison using the existing manual process.

The images in Figure 15 show the results of three carcasses where the chine was removed.

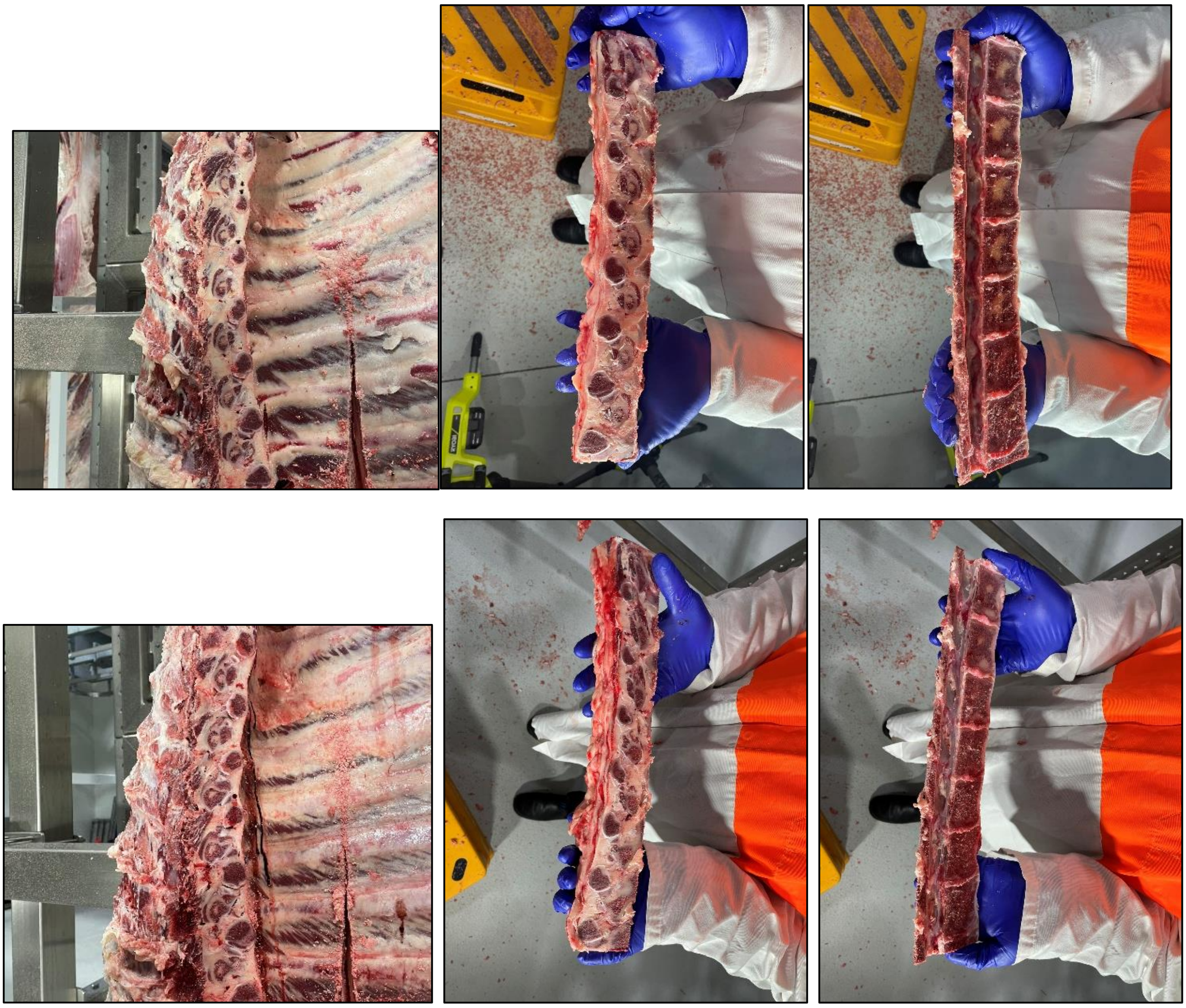


Figure 15- Chine cut results showing carcase after chine was removed, as well as front and back of removed chine bone

6.10.4 Chine Removal Yield Assessment

The yield assessment was performed by KGF using the trial carcases. The first 40 robot-cut right-hand sides were sent to the boning room to allow the boning room team to practise and become familiar with the new cutting method and product presentation. This was important because the robot-cut chine removal process changed the way the cube roll was presented for downstream removal compared with the existing manual method.

After the practice group had been processed, the final 10 robot-cut right-hand sides were sent to the boning room for comparison against their corresponding left-hand sides. The left-hand sides were boned out using the existing method and used as controls. This comparison was used to assess whether the robotic chine removal process reduced cube roll loss while still achieving the required chine removal outcome.

6.10.5 Square Cut Cube Roll - Tool Changeover and Calibration

Following completion of the high-volume chine removal demonstration, the robot was reconfigured from the chine-removal arrangement to the arrangement required for the Square Cut Cube Roll application.

This changeover involved removing the chine removal tool, installing and assembling the square cut cube roll tool, and relocating the vision camera to its designated position relative to the tool assembly. The changeover supported the MS9 objective of demonstrating a semi-automatic cutting approach and verifying the associated tooling, robotic and vision-system requirements on stationary beef sides.

Eye-in-Hand Camera Calibration

Because the camera was mounted directly to the robot tooling assembly, its position and orientation relative to the robot flange had to be accurately determined before camera-selected locations could be converted into robot movements. A calibration was therefore completed after the tool and camera had been installed.

The completed calibration established the camera-to-flange relationship required for vision-guided tool positioning.

Integrated Calibration Validation

The combined camera and tooling calibrations were validated using a stationary beef side positioned within the camera field of view. Test points were selected from the camera image and converted through the calibrated camera-to-robot transformation. The robot was then instructed to move the tool to the corresponding physical location on the beef side.

This test was repeated at multiple locations across the visible surface. This result demonstrated that the eye-in-hand camera calibration and tool calibration were operating correctly as an integrated system.

The validation confirmed that image-selected points could be accurately transformed into robot movements using the installed tool. This provided the calibration accuracy required for subsequent semi-automatic cut-path definition and supported the MS9 objective of demonstrating the tooling, robotic and vision approach for Square Cut Cube operations.

6.10.6 Square Cut Cube Roll Demonstration

Following completion of the tool changeover and calibration, a Square Cut Cube Roll demonstration was performed on stationary beef sides. The purpose of the demonstration was to verify the complete semi-automatic workflow, including vision data acquisition, operator-assisted cut-path definition, transformation of the selected path into robot coordinates, and execution of the cut using the calibrated tool.

Approximately five beef sides were processed during the demonstration. The robot was used to open both the target cuts. Photographs and video were recorded to document the robot motion, interaction between the tool and the product, and the resulting cuts.

Semi-Automatic Cut-Path Definition

For each cut, the beef side was positioned and stabilised within the robot work area and camera field of view. Camera data were then acquired and used to identify the anatomical region through which the cut was to be performed.

The resulting three-dimensional path was represented within the acquired point cloud. This provided a visual means of checking the location of the proposed cut relative to the surface of the side and illustrating the position of the tool as it progressed along the path.

Grading and 5/6 Cut Demonstration

The demonstration assessed the ability of the robot to open both the target cuts using paths defined from the camera data.

Both cuts were successfully demonstrated. For both the target cuts, the tool aligned with the selected region and followed the intended path to open the existing scribe cut. The point-cloud data were also used to illustrate the position and orientation of the tool throughout each motion.

The successful execution of both cuts demonstrated that the vision-defined paths could be converted into practical robotic movements and that the combined camera and tool calibrations provided sufficient alignment for the demonstration.

Demonstration Outcomes

The Square Cut Cube Roll demonstration was successfully completed on approximately five beef sides. Across the demonstration, the robot was used to open both the grading cut and the five/six rib cut using paths defined from the vision data.

The following outcomes were demonstrated:

- Control points could be selected from the camera data to define cut paths for individual beef sides.
- The selected camera-space points could be accurately transformed into robot coordinates using the eye-in-hand calibration.
- The calibrated tool could be positioned at the selected start location with the required orientation.
- The robot could insert the tool and follow the generated three-dimensional path to open the grading and five/six cuts.
- The complete process could be repeated across multiple beef sides despite variation in product shape and presentation.

The trial therefore demonstrated the feasibility of the proposed Square Cut Cube Roll automation workflow.

6.10.7 Yield Review

Small yield assessment of optimised vs current processed showed a calculated profit gain per body in current market.

Operational efficiencies for boners were not affected from the optimised bodes but boners noted the need to adjust technique to account for the rib cage falling when they got to the chine area that usually holds to the dorsal edge of the cube roll to the rib cage. Feedback overall was positive & most boners advised that it was reducing time & workload slightly allowing them to focus on cutting lines.

Allocations for the depth optimisation & tuning should be budgeted for in the next stage.

6.10.8 Next stage development, commercialisation, extensions and adoption discussion with AMPC

Upon completion of the Chine Removal and Square Cut Cube demonstrations, a meeting was held between AMPC, KGF and Intelligent Robotics regarding the next stage of the work, which will involve a project to develop a production system for KGF.

The trials successfully demonstrated the ability to remove the chine, and perform the two square cut cube roll cuts using the proposed concept. Based on this, the production concept was developed and presented to KGF and AMPC. The high-level scope of the next stage project was discussed.

The next-stage project is intended to translate the R&D outcomes from this and previous development work into an operating production system at KGF's Kilcoy plant. Chine Removal has been a long-sought candidate for automation, with the Square Cut Cube Roll automation acting as an enabler for this while providing further yield benefits. The proposed system provides a pathway to demonstrate production-scale performance and assess broader adoption across industry. Combining Square Cut Cube, Chine Removal and IR-SCRIBE automation may also strengthen the overall value proposition by increasing the automation capability delivered within the available footprint and capital investment.

7.0 Conclusions

This project successfully demonstrated the technical feasibility of using robotic systems to perform both chine removal and the Square Cut Cube Roll operations on stationary beef sides. The trials confirmed that the proposed approaches could complete the required cuts using robot-mounted tooling, carcase-specific path definition, vision assistance and controlled stabilisation. The final demonstrations showed that both processes were successful and provided sufficient confidence to progress from controlled testing into the development of a production-scale system.

For the Square Cut Cube Roll operation, the project demonstrated that a robot-mounted tool could extend the 5/6 and grading scribe cuts through the eye muscle while producing clean and consistent cut faces. The trials also showed that the tool could be reoriented while inside the cut to follow the rib and complete the required grading cut profile. Stabilisation requirements were also simplified during the project.

For chine removal, the project demonstrated that the custom robot-mounted tool could remove the chine using a cut path adapted to individual carcases. The work progressed from manually taught paths to a vision-guided process in which anatomical points were selected from images and converted into robot movements. The resulting path-generation method accounted for the size and shape differences across carcases and allowed the tool path to be adjusted for each side.

A practical method was also established for assessing the yield effect of robotic chine removal. Robot-cut right-hand sides were processed alongside corresponding left-hand control sides, with an initial group used to familiarise boning-room operators with the changed product presentation before the final comparison was performed. Most importantly, this process demonstrated that the presentation of the beef side with the cube roll removed was able to be boned out downstream in a manner that could capture the yield benefit targeted.

The results support progression to a next-stage R&D project to design, install and commission a production system at Kilcoy. The principal feasibility risks associated with tooling, robotic access, cutting methods, carcase variation, stabilisation and cut-path generation have been addressed sufficiently to justify this step.

For processors and other industry stakeholders, the project provides a credible pathway toward automating tasks that currently expose workers to powered saws, knives, repetitive movements and difficult manual cutting. Successful production implementation could improve workplace safety, reduce dependence on scarce skilled labour, increase consistency and protect the recovery of high-value product. The next project should therefore focus on translating the demonstrated processes into a robust production system and validating their commercial and operational performance over significant throughput.

8.0 Recommendations

1. **Progress to a production-scale R&D project at Kilcoy**

AMPC, Kilcoy Global Foods and Intelligent Robotics should progress to the next-stage project to design, install and commission an integrated production system. This is the appropriate next step because the core cutting methods have been demonstrated successfully, while the remaining questions relate mainly to sustained operation under production conditions.

2. **Validate performance over sustained production volumes**

The next project should assess the system across a sufficiently large and representative volume of carcases. Testing should confirm repeatability across carcase sizes and presentations, production cycle time, availability, reliability, cut quality and the frequency of operator intervention. The current project resolved the principal feasibility risks, but these operational factors cannot be fully demonstrated through further low-volume offline testing.

3. **Refine tooling, tool monitoring and changeover arrangements**

Further development should focus on production-ready tooling. This should include tool life, wash frequency, maintenance, tool storage and methods for detecting wear or poor cutting performance.

4. **Integrate hygiene, cleaning and maintenance into the production design**

The next system should be designed around the plant's cleaning schedule and food-safety requirements rather than treating washdown as a later addition. Tool washing frequency, wash tanks, camera and electrical protection, access for inspection, and safe maintenance procedures should be included in the cycle-time and availability assessment. Kilcoy should define the required cleaning frequency early so that its effect on throughput and labour can be assessed.

5. **Plan installation and commissioning to minimise production disruption**

Intelligent Robotics and Kilcoy Global Foods should develop a detailed installation and commissioning plan. The next-stage scope should include sufficient commissioning and production-support time to progressively increase volume without creating unacceptable operational risk.

6. **Prepare for broader industry adoption and extension**

AMPC should use the production results to communicate demonstrated safety, labour, yield and operational outcomes to the wider red meat industry. Extension activities should include processor demonstrations, video case studies, technical summaries and guidance on plant layout, prerequisite processes and expected implementation requirements. Broader adoption should be promoted once production-volume performance and the commercial case have been validated.