

Microwave measuring fat and muscle depth of beef primals

Project code
2024-1123

Prepared by
Sean Starling

Date submitted
01/10/2025

Published by
AMPC

Date published
01/10/2025

Contents

Contents	2
1.0 Abstract	3
2.0 Executive summary	3
3.0 Introduction	4
4.0 Project objectives	5
5.0 Methodology	6
6.0 Results	11
7.0 Discussion	11
8.0 Conclusions	12
9.0 Recommendations	12
10.0 Project outputs	13
11.0 Bibliography	13
12.0 Appendices	14
11.1 Appendix 1 – Inception Meeting	14
11.2 Appendix 2 – Murdoch Final Report	15

Disclaimer The information contained within this publication has been prepared by a third party commissioned by Australian Meat Processor Corporation Ltd (AMPC). It does not necessarily reflect the opinion or position of AMPC. Care is taken to ensure the accuracy of the information contained in this publication. However, AMPC cannot accept responsibility for the accuracy or completeness of the information or opinions contained in this publication, nor does it endorse or adopt the information contained in this report.

No part of this work may be reproduced, copied, published, communicated or adapted in any form or by any means (electronic or otherwise) without the express written permission of Australian Meat Processor Corporation Ltd. All rights are expressly reserved. Requests for further authorisation should be directed to the Executive Chairman, AMPC, Suite 2, Level 6, 99 Walker Street North Sydney NSW.

1.0 Abstract

Processors often face financial claims from retailers when excess fat must be trimmed from primals such as striploins. Current industry methods for estimating fat depth rely on single-point measurements that can be inaccurate, leading to inefficiencies and lost value. This project investigated whether microwave scanning technology could provide a more accurate, non-invasive method for measuring subcutaneous fat depth and help guide trimming to meet market specifications.

To test this, 100 beef striploins were scanned using a custom microwave system with four antennas operating over a wide frequency range. Each loin was sliced into steaks, and fat depth was manually measured at standard points using imaging software. These measurements were then compared against the microwave signal data using advanced machine learning models designed to optimise prediction accuracy.

The results showed that the microwave system, combined with ensemble machine learning, achieved strong predictive performance. Accuracy improved when fat measurements were averaged across multiple points, with overall prediction error reduced to within approximately ± 3 mm of actual fat depth. Antennas two and three consistently performed best, and the system produced results comparable to or better than traditional manual scoring methods.

This project confirmed the technical feasibility of microwave scanning for objective fat depth measurement. With further development and adaptation for real-time use in abattoirs, the technology could reduce trimming errors, minimise waste, and increase processor profitability. Ultimately, microwave scanning offers a pathway to more precise, automated carcass grading and boning room operations.

2.0 Executive summary

This project investigated the use of non-invasive microwave scanning combined with advanced image analysis and machine learning to measure subcutaneous fat depth in beef striploins at JBS Australia. The problem being addressed is the current reliance on single-site fat measurements (such as rib-eye or P8 sites), which often lead to inaccurate estimates of fat depth across an entire cut. This inaccuracy causes processing inefficiencies, higher labour costs, and potential financial penalties from retailers when excess fat must be trimmed. The primary audience for this research includes red-meat processors, retailers, and levy payers, who all stand to benefit from more objective and precise fat measurement systems. The results of this project will be used to guide industry investment in developing a commercial microwave-based fat grading system that improves processing efficiency, reduces waste, and increases consistency in meeting market specifications.

Objectives

The project aimed to:

- Develop and evaluate a microwave-based scanning system for predicting fat depth in beef striploins.
 - Compare different fat depth measurement approaches to identify the most reliable method.
 - Validate the potential of machine learning models to improve accuracy.
- These objectives were successfully achieved, with the research confirming technical feasibility and highlighting pathways toward real-time, commercial application

Methodology

- **Sample Collection:** 100 striploins were scanned using a four-antenna microwave array (100 MHz–5.4 GHz).
- **Ground Truthing:** Each loin was sliced into 30 mm steaks, and fat depth was manually measured at five standard points using RGB imaging.
- **Data Analysis:** Microwave signal data were processed using ensemble machine learning models (stacked regression of Partial Least Squares, Random Forest, and Support Vector Machines) to predict fat depth across single-point and multi-point targets

Results / Key Findings

- Prediction accuracy improved when multiple fat points were averaged, aligning with the physical footprint of microwave signals.
- Accuracy (R^2) increased from 0.31 (single point) to 0.72 (multi-point), while error (RMSEP) reduced from 5.62 mm to 2.87 mm.
- Antennas 2 and 3 consistently produced the best results.
- Ensemble models outperformed individual models, confirming the strength of the stacked approach

Benefits to Industry

The research demonstrates that microwave scanning can provide objective, repeatable fat measurements. This technology has the potential to:

- Reduce costly trimming claims from retailers.
- Improve labour efficiency by guiding boners to precise trimming specifications.
- Provide a scalable, non-invasive solution for grading meat quality.

Future Research / Recommendations

Further work should:

- Expand the dataset to include greater variation in carcass sizes and fat depths.
- Automate fat point detection with deep learning and integrate real-time processing.
- Develop imaging outputs (e.g., heatmaps) to visually guide boners during trimming.
- Build and test an abattoir-ready prototype for commercial rollout

In summary, this project establishes a strong technical foundation for microwave-based fat measurement in beef processing, offering clear benefits to processors, retailers, and levy payers through improved accuracy, efficiency, and cost savings.

3.0 Introduction

The Australian red meat industry faces a long-standing challenge in objectively and accurately measuring subcutaneous fat depth in beef primals. Traditionally, trimming decisions are made by skilled operators using visual estimation and knives (e.g., the GR knife), which introduces variability and subjectivity into the process.

Over-trimming reduces processor yield and erodes profitability across the supply chain, while under-trimming exposes processors to costly retailer claims for excess fat, rework, and penalties.

These inefficiencies also contribute to a higher carbon footprint due to wasted product and energy inputs. Thus, the lack of an objective, rapid, and non-destructive measurement system represents a significant knowledge and technology gap in meat processing.

This project sought to address that gap by evaluating the use of microwave array technology—originally developed for lamb fat depth measurement at Murdoch University—for application in beef primals. Specifically, it tested whether a four-antenna Vivaldi patch array could predict fat and muscle depth in striploins and cube rolls with sufficient accuracy to inform trimming, automate fat removal, or verify compliance with fat specifications for quality assurance.

The research aimed not only to validate the technical feasibility of microwave imaging combined with machine learning but also to establish a new, non-invasive method of objective grading for beef. By integrating calibrated microwave signals, image analysis, and ensemble prediction models, the study represents a step toward precision processing technologies that could fundamentally reduce waste and improve yield consistency across abattoirs.

The primary research question was: *Can microwave scanning, coupled with imaging and machine learning, reliably predict fat depth in beef primals at a level of accuracy suitable for commercial processing?* This question is critical because current industry practices lack real-time, objective tools for fat assessment, despite evidence that objective carcass measurement technologies improve market transparency and processing efficiency (Anderson et al., 2020; Gardner et al., 2018). By answering this question, the project has direct relevance to processors, retailers, and supply chain stakeholders, particularly those supplying both domestic and export supermarkets where fat claims and trimming inconsistencies remain costly.

The intended outcomes are designed for three key audiences:

- **Meat processors**, who require tools to improve yield, reduce retailer disputes, and enhance operational efficiency.
- **Retailers and consumers**, who will benefit from greater product consistency and reduced waste.
- **Industry bodies (e.g., AMPC, MLA)**, who seek scalable innovations that support sustainability and competitiveness in global markets.

What makes this project unique compared to earlier initiatives is its focus on adapting microwave technology beyond carcass fat measurement to the **primal level**, integrating real-time imaging and advanced machine learning. While ultrasound, CT scanning, and hyperspectral imaging have been explored in meat science (Barbin et al., 2012; Brøndum et al., 1998), they are often too slow, costly, or impractical for routine commercial use. Microwave systems, by contrast, offer rapid, portable, and non-destructive scanning that can be integrated into abattoir workflows at scale. This study therefore represents a pioneering step toward a commercial prototype capable of supporting both human trimmers and automated systems in the red-meat sector.

Ultimately, the results of this research will be used to guide the development of a next-phase commercial prototype, expand datasets for improved predictive accuracy, and explore integration into automated trimming systems. If successful, this technology has the potential to deliver a transformative shift in the way fat trimming and specification compliance are managed, positioning Australian processors at the forefront of objective measurement innovation.

4.0 Project objectives

The project objectives ultimately are to:

- Ascertain if the current lamb fat depth microwave technology can be leveraged for the accurate measurement of beef primal fat depth, which can then inform either trimmers on where to trim, automation on where to trim and or finally, as a final product specification fat depth checking solution for QA.

This project is Phase 1 only and aimed at an investigation level only. The investigation will be achieved by a methodical approach to:

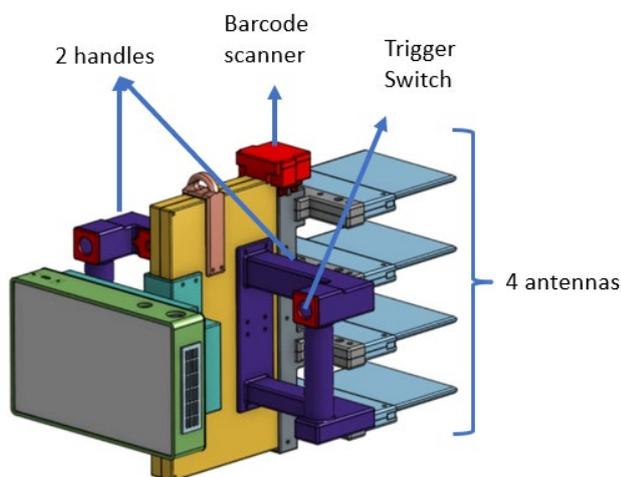
- Test and train a prediction of the fat and muscle depths of the striploin using a microwave array system at JBS.
- Test and train a prediction of the fat and muscle depths of the cube rolls using a microwave array system at JBS.

5.0 Methodology

The experiment consists of two parts, one focused on striploins, and the other focused on cube rolls. Striploins (n=150) and cube rolls (n=150) will be selected from the portion-cutting room to maximise the range in fat depth and weight. These will be microwave scanned using the beef microwave array prior to portion cutting. Following portion cutting, individual steaks will be photographed using an iPhone mounted upon a stand to image each steak in-sequence to match the anatomical sampling point acquired using the beef microwave array. A steel ruler within each image will enable geometric calibration and hence calculation of eye muscle area, eye muscle depth, and fat depth. This will result in a dataset for both striploins and cube-rolls within which the Murdoch team will train an algorithm to predict fat depth, eye muscle depth, and eye muscle area for each steak within each primal. A range of analytical steps will be required, including establishing robustness of the calibration procedure, microwave signal analysis to generate microwave prediction vectors, iPhone image analysis to determine dimensional traits such as fat depth, eye muscle depth, and eye muscle area, and lastly development of a machine learning algorithm to predict the dimension traits. A more comprehensive description of these procedures is provided in the “Detailed Methodology” section below.

Detailed Methodology

Figure 1 shows the microwave array system for measuring beef strip loin fat, muscle depths and CT composition. The system consists of four Vivaldi patch antennas (VPA) covered in 3D-printed casing connected to a vector network analyser. The system has a Windows operating system and an automated Python code to capture the measurements using a trigger switch. The system has two handles to enable the operator to place the array system on strip loins and the trigger switch is located on the right handle for easy access to take the measurements. The system has a rechargeable lithium battery pack and a built-in barcode reader for carcass tag identification.



The signals are captured in the form of reflection

a



b

Figure 1. Beef array system a) design view b) manufacture view

The four-antenna array system is placed on the strip loin to capture the reflected signals. coefficients (S11).

Each measurement on the strip loin will produce four reflection coefficients (S11, S22, S33, S44), and each signal will have 531 discrete frequencies.

Figure 2 shows the magnitude and phase of the frequency response, the reflection coefficients from all four antennas achieved -10dB across the frequency range of 1.4 – 5.2 GHz. These are some of the prediction vectors used to determine fat depth and muscle dimensions.

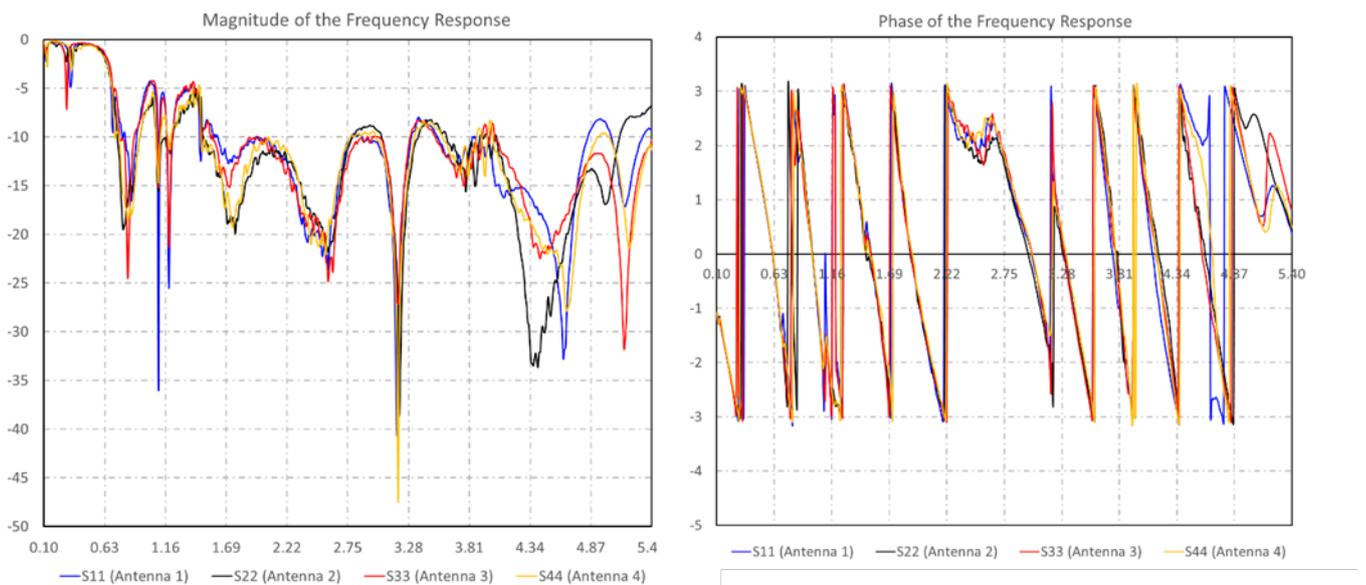


Figure 2. Magnitude and phase of the frequency response of the antennas

System calibration

Before taking the actual measurements on strip loins, the array system must be calibrated for all 531 frequencies, across all entities (S parameters) to correct and remove the systematic errors and antenna response errors. The standard method to calibrate the microwave array system is to perform open, short and load measurements using a custom-made Python program loaded in the system. Figure 3 shows the array system performing open, load and short calibration before actual carcass/strip loins scanning. This calibration has been optimised for a single antenna system used in beef carcasses. Some analysis will be required to adapt the calibration to the 4-antenna scenario.

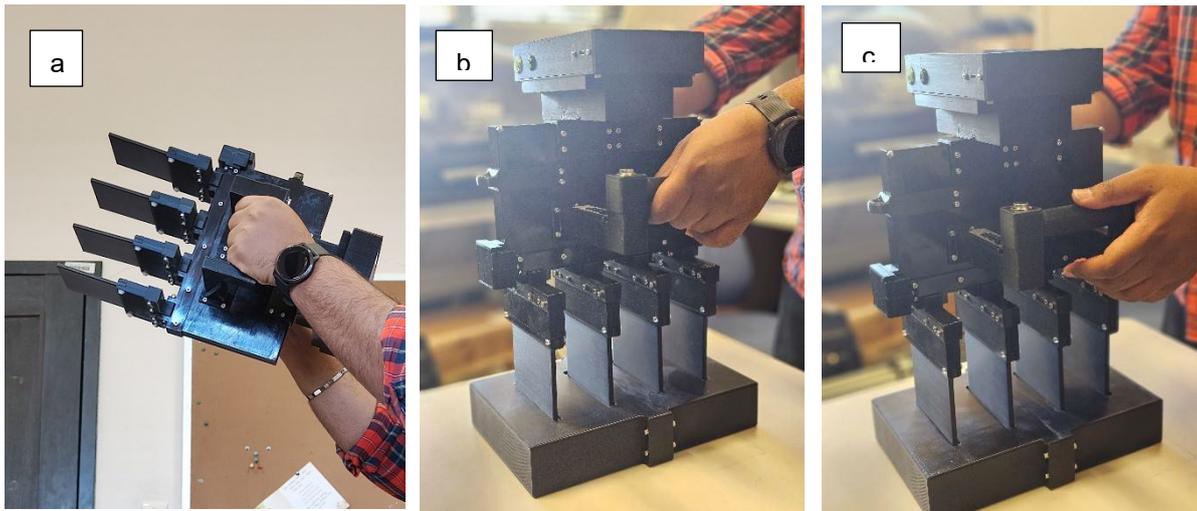


Figure 3. shows the microwave system performing a) open b) load c) short measurements.

Experiment 1

Using the array system to measure the strip loins' fat and muscle depths before cutting them into slices at JBS.

The experiment consists of two people from Murdoch University travelling to JBS and setting up the experiment to capture the Microwave array system data of Striploin samples. The steps involved in experiment 1 are:

- Step 1: In the first step, the striploin samples would be selected to maximise the range in fat depth and weight. These would be selected based upon vernier calliper measured fat depth. The point of selection would be in the boning room prior to the portion cutter, but will require JBS input to minimise disruption to plant processing. Figure 4 shows examples of the fat depth range required in beef striploins.

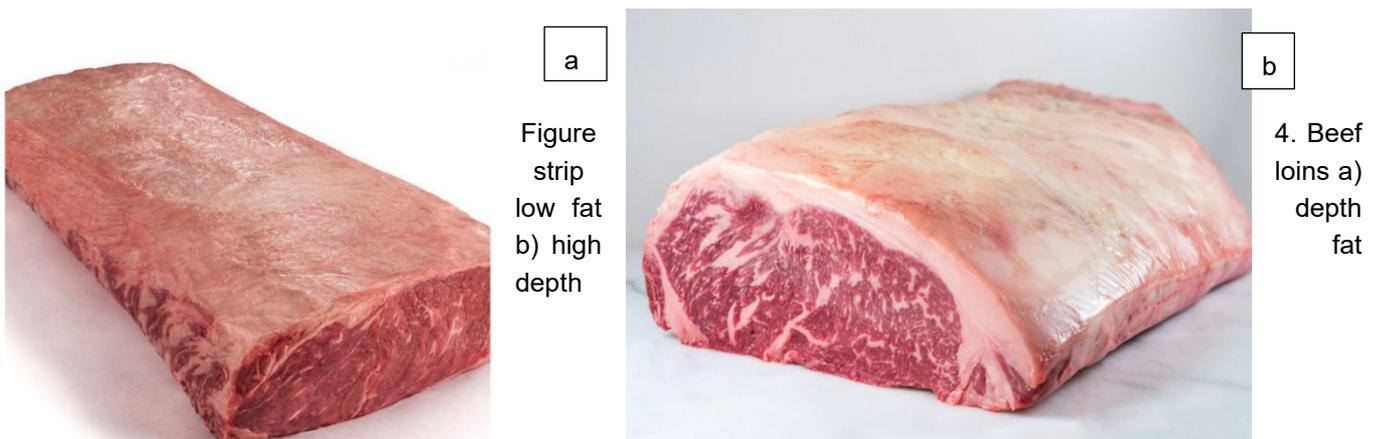


Figure strip
low fat
b) high
depth

4. Beef
loins a)
depth
fat

- Step 2: The selected strip loins will be microwave-scanned as shown in figure 5, by placing the array system on top and centre of the strip loin. A1, A2, A3 and A4 are 4 antennas of the system by using the trigger switch of the array system the measurements are captured and saved in the system.

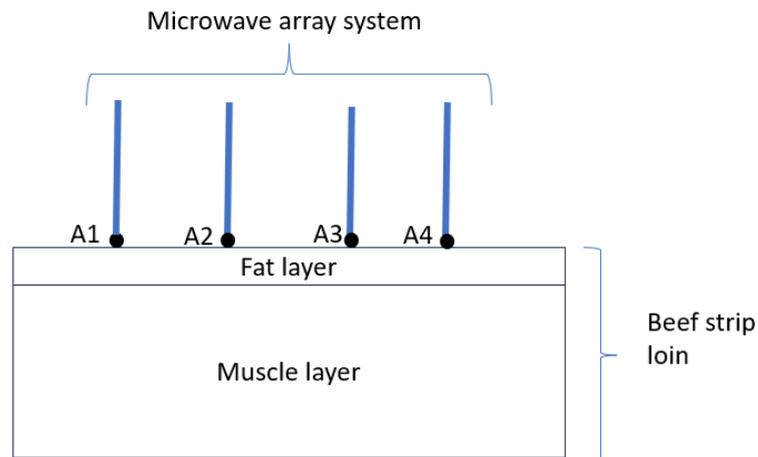


Figure 5. Microwave array system measuring beef strip loin fat and muscle depth.

- Step 3: Then microwave scanned and tagged strip loins are sent for portion cutting.
- Step 4: An Android/iPhone-operated mobile phone camera will be set up and connected to a computer to capture the photographs of portioned steaks. A series of photographs are taken in a sequence measuring the steak fat depth, eye muscle depth and eye muscle area of each portion cuts using a steel ruler in each image for calibration as shown in Figure 6.

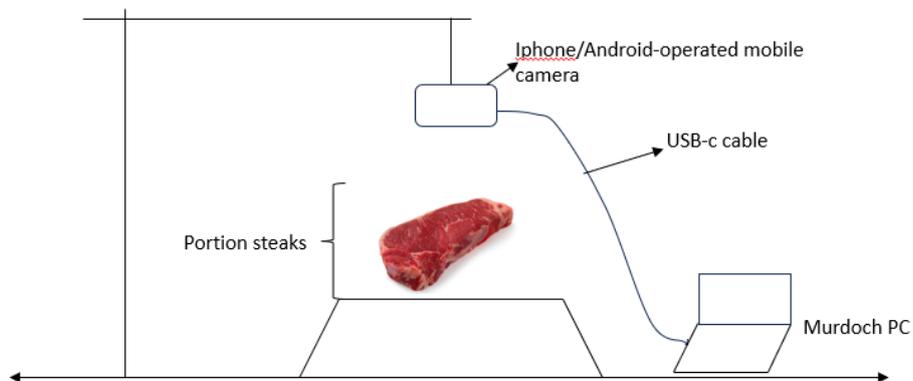


Figure 6. Photograph the portion of the steaks using an iPhone/Android-operated mobile phone.

- Step 5. Once the vernier callipers measurements and photos are taken, data gets stored in a PC and brought back to Murdoch University for image and data analysis.

Experiment 2

The experimental procedure described in Experiment 1 will be repeated for cube roll primals.



Figure 7. Beef cube roll.

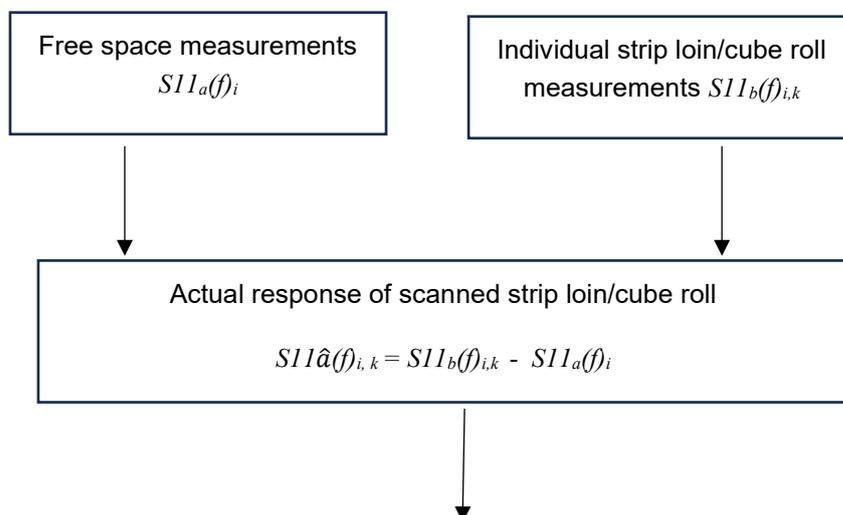
Image processing/Signal processing of microwave and photograph data

The microwave and photograph data collected at JBS will be brought back to Murdoch University for image and signal processing.

Microwave signal processing.

The free space ambient reflection coefficient $S11_a(f)_i$ is recorded before, during and after the strip loin/cube roll measurements. For every measurement, the system recorded 531 discrete frequency points. $S11_a(f)_i$ indicates the complex number of the reflection coefficient of free space where $i=1,2,3, \dots, 531$ discrete frequencies (f). Meanwhile, $S11_b(f)_{i,k}$ indicated the complex number of reflection coefficients of scanned strip loin/cube rolls where $i=1,2,3, \dots, 531$ discrete frequencies (f) and $k = 1, 2, 3, \dots, n$ strip loins/cube rolls scanned. To obtain the actual response $S11\hat{a}(f)_i$ of the individual scanned strip loins/cube roll fat and muscle depths subtract $S11_b(f)_{i,k}$ from $S11_a(f)_i$. $S11\hat{a}(f)_{i,k}$ indicate the complex number of the actual reflection coefficient of strip loins/cube rolls scanned.

Figure 10 shows the flow diagram of data processing steps to obtain the magnitude of the reflection coefficient $|S11\hat{a}(f)_{i,k}|$ of actual fat and muscle depths of individual strip loin/cube roll. Signal processing steps are achieved by using MATLAB.



$$|SII\hat{a}(f)_{i,k}|$$

$$i = 1,2, .. 531 \ \& \ k = 1,2, n$$

Figure 10 Flow diagram of data processing of microwave array system

Photograph image analysis.

Images of photographed steaks will be analysed using image J software to calculate fat depth, eye muscle depth and eye muscle area. This will provide source data to train the microwave to predict the fat depth, eye muscle depth and eye muscle area.

Statistical analysis/Machine learning predictions

A set of various statistical equation will be used to predict the strip loin/cube roll fat and eye muscle depth and eye muscle area. The 531-discrete frequency domain reflected microwave signals data is saved in XL and imported into Weka for prediction analysis. The prediction equation is constructed and analysed in WEKA (Waikato Environment for Knowledge Analysis Version 3.8.5 © 1999-2024) by using four signal components. A leave-one-out cross validation procedure will be used for testing and training of the data. The relationship between actual and predicted values from the leave-one-out cross validation procedure will be reported as R-Square (R²) and root-mean-square-error of the prediction (RMSEP) for precision of prediction.

6.0 Results

The project successfully developed and validated a non-invasive microwave scanning system combined with image analysis and ensemble machine learning to predict subcutaneous fat depth in beef striploins. Using a four-antenna Vivaldi patch array scanning across 531 microwave frequencies, 100 striploins were measured and analysed. Multi-point fat depth averaging (9–15 points) achieved the highest accuracy, with R² values up to 0.72 and RMSEP under 3 mm. Antennas 2 and 3 consistently performed best. The study demonstrated clear technical feasibility, establishing a strong foundation for the development of a commercial system.

7.0 Discussion

All Australian red meat processors are required to trim primals to a specification depth level. This is done by the best guess of an operator, and the actual fat depth is not know until the primal is sliced into steaks.

For processors that supply both domestic and international supermarkets, over fat in a primal is one of the largest claims made by those next in the value chain.

One Australian supermarket chain has staff post all portioning machines, cut off excess fat, and then weigh and photograph the trimmed fat.

The processor is then sent a claim for the weight of fat, plus the labour component.

In other situations, staff are trimming too much fat off, meaning that this excess trimming is costing the entire supply chain profits, efficiencies, and arguably carbon footprint.

The integration of precise RGB imaging with calibrated microwave signal acquisition allowed for accurate fat depth mapping. Synchronisation of antenna positions with known fat measurement points improved prediction reliability. The stacked ensemble machine learning approach (PLSR, SVM, RF) outperformed single models, effectively handling the complex interaction between microwave signals and tissue structure. Multi-point averaging aligned better with the antenna's electromagnetic footprint, reducing noise from localised fat variations.

The results compare favourably with traditional fat scoring methods, offering a more objective, repeatable solution. Future improvements include automated fat line detection, real-time signal calibration, larger and more diverse datasets, and integration into abattoir workflows.

8.0 Conclusions

Microwave imaging combined with machine learning provides a robust, non-destructive, and accurate method for estimating fat depth in beef striploins. The technology shows significant promise for guiding boners to trim products to exact specifications, reducing waste, and improving yield consistency. The study confirms the viability of this approach for industrial applications, pending further development and commercial adaptation.

9.0 Recommendations

JBS and Murdoch will recommend that this work be continued under a second project, for which a submission for consideration is being prepared. More detailed recommendations specific to the design of the next submission are:

Data Expansion – Increase sample size and variability to enhance model robustness and capture a broader range of fat depths and striploin dimensions.

Automated Processing – Implement AI-based fat cap detection, automated microwave signal calibration, and real-time image generation to remove manual steps.

System Integration – Develop a commercial-grade prototype with robust hardware suited for abattoir conditions and compatibility with conveyor or robotic systems.

Visual Guidance Tools – Create topographical heatmaps and 3D fat distribution images to aid boners in trimming decisions.

Phased Development – Progress through structured phases from dataset expansion to full automation and prototype deployment.

10.0 Project outputs

The project delivered a range of tangible outputs, spanning research deliverables, industry reporting, and technical communications. These outputs are outlined below.

1. Research & Technical Deliverables

- **Final Technical Report:** A comprehensive final report was prepared and submitted to AMPC (July 2025), including detailed methodology, statistical modelling, results, and recommendations for further development
- **Microwave Imaging System Prototype:** A custom-built microwave scanning system using a four-antenna Vivaldi patch array was developed and trialled on 100 beef striploins, producing a validated technical proof-of-concept.
- **Machine Learning Models:** Ensemble stacked models (PLSR, SVM, RF) were trained and validated, demonstrating prediction accuracies of R^2 up to 0.72 and RMSEP below 3 mm.
- **Dataset Creation:** A curated dataset of 100 striploins (sliced into 30 mm steaks), with fat depth measured at five points per steak, supported modelling and evaluation.
- **Simulated Visual Outputs:** Heatmaps and 3D surface plots of fat distribution were generated to demonstrate future potential for boner-guidance applications.

2. Industry Engagement & Extension Activities

- **Reporting to AMPC:** Project milestones and the final report were formally submitted and approved by AMPC as part of the project's co-investment framework.
- **JBS Australia Engagement:** Trials were conducted at the JBS Brooklyn site, ensuring direct alignment with processor needs and operational realities.

3. Communication & Knowledge Sharing

- **Executive Summary & Abstract:** Industry-ready summaries were prepared to ensure accessibility for non-technical stakeholders.
- **Potential Industry Articles:** The findings provide content for future AMPC newsletters and industry publications to inform levy payers of technology feasibility.
- **Extension Material:** Figures, tables, and explanatory diagrams (e.g., antenna layouts, fat depth measurement points, simulated heatmaps) were produced to support presentations, training material, and industry dissemination.

11.0 Bibliography

Intentionally left blank.

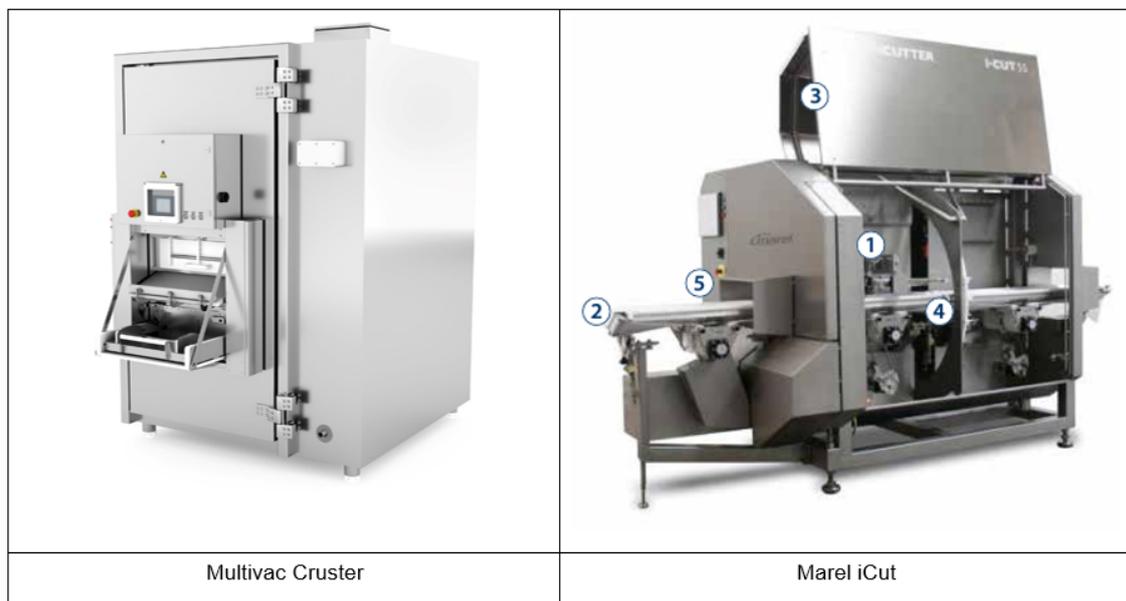
12.0 Appendices

11.1 Appendix 1 – Inception Meeting

On Wednesday, 27th November 2024, Dr Graham Gardner and Stephen Connaughton attended the Brooklyn facility, hosted by Sean Starling, to visually observe both the beef fabrication room (where untrimmed primals will be collected from) and the Brooklyn Value Add (VA) processing facility that has a Multivac cruster (primal surface crusting) and Marel iCut55s that will be used to equal thickness portioning of the primals selected.

The process and path for collecting untrimmed primals from the fabrication floor down to the VA room were walked and agreed upon as suitable, and the crust freezer and Marel iCut were agreed upon as suitable processing equipment items for the project and to proceed to Milestone 2.

From this process, the Murdoch team has agreed to undertake the in-room trials in Brooklyn no later than the end of February 2025.



There is also the option to use a bone-in automated bandsaw within the VA room if the project team wants to evaluate the possibility of the technology working on bone-in products such as a short loin. The iCut 55 is for

boneless products, whereas the Mainali RB-1, pictured below, is for bone-in product steak portioning.



11.2 Appendix 2 – Murdoch Final Report

Provided as a separate attachment to this reports email.