Final Report

AUSTRALIAN MEAT PROCESSOR CORPORATION

Hot Beef Cutting

Hot Beef Cutting Trial Study

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1.0 Executive Summary

There are many barriers to adoption of new technologies within the red meat industry, including changes of processes and risk associated with all new technologies. In addition to this, a major barrier is the return on investment (ROI) of a system. One way that the ROI can be improved, is by increasing the consistency/accuracy of the system, allowing yield to generate more value. As a result, the accuracy at which scribe lines can be placed on the carcase is critical. This project will focus on the concept of manually scribing hot beef carcase sides on a backing board whilst assessing the level of movement experienced during and after placement of scribe lines.

Throughout this project, multiple hot beef carcase sides were placed on a backing board with various angular and surface friction configurations to help support and stabilise the carcase sides during a cut sequence.

Figure 1- Trial Rig Design and Subsequent Assembly

Once installed on site, trialling was performed in a range of different configurations and methodologies.

During the trials, the carcase movement was measured for each stabilisation configuration. Based on the results obtained, the optimal backing board angle to ensure adequate carcase stability both during and after each cut was assessed. Analysis was performed on carcase movement in between cuts, and during cuts.

The main purpose of these trials was to help us understand how ROI can be improved by increasing the consistency and accuracy during scribe cut operations on a hot carcase, thus allowing yield to generate more value for processors in the industry. There were a few key take-aways from the trials conducted: -

- The magnitude of carcase movement between and during cuts and whether the calculated cut positions needed to be adjusted between cuts.
- Requirements for support surface to ensure sufficient stability.
- Optimal support angle required to adequately support the carcase during cutting.
- Cut technique has a large impact on the carcase movement/stability during and after a cut cycle.

The next step is to transfer these learnings to an automated robotic cutting application which can perform these scribing cuts accurately by ensuring the carcase is sufficiently supported between each of the spine cuts.

2.0 Introduction

The automation of beef scribing is a significant target area for the red meat industry. While there is a significant amount of previous work investigating the factors relating to performing these cuts on cold carcases, the considerations required for a hot automated beef scribing system, operating on unchilled, pre-rigor carcases, has not been investigated. This project sought to understand how hot carcases react while spine scribes are applied to the carcase, and to perform a preliminary exploration of the stabilisation requirements for performing the cuts, as well as whether the carcase moves in between cuts.

This project focuses on the methods of increasing accuracy of cuts on a hot beef carcase while limiting excessive carcase deflection during cut cycles. Within this field of study, there are also considerations given to:

- How to stabilise moving carcases
- What cutting techniques are used by the operator to perform efficient cuts

At the conclusion of this project, we will gain an understanding of what requirements are critical to ensure cut accuracy is met on an automated system. It will also give us a list of criteria and parameters to transfer over onto our robotic cutting program to ensure we employ the most efficient cutting techniques so as to minimise carcase deflection during cuts.

3.0 Project Objectives

The core objective within the scope of this project is to perform trials whereby hot beef sides are supported whilst scribing cuts are performed on it. The amount of movement experienced during, and after the placement of cuts will then be observed. Any potential methods to reduce this deflection can also be explored.

There are a multitude of benefits produced within this project that are identified within AMPC's 2020-2025 Strategic plan, including:

1) Removing staff from dangerous operations, via hands-off processing.
2) Increasing safety and wellbeing, by reducing the high-risk nature or certain processing operations.
3) Attraction of people to the industry via demonstrating a wide range of technological operations.
4) Retention of people within the industry by improving working conditions.
5) Developing tasks that require higher skills and intellect.
6) Increasing carcase primal profitability through optimisation
7) Enabler for acquiring product and processing formation in order to leverage data insights.

Automated Beef scribing will aim to make a significant impact upon all seven by acting as an enabler for wider roll-out of automated beef scribing to include applications/sites where it is desired to perform the cuts pre-chill. One particularly high-value cut is the placement of the grading cut. To allow sufficient time to bloom, this is often done in the chillers with a hacksaw or pneumatic saw to first break the spine before it is knifed out. Many sites do not have sufficient space for this scribing cut to be placed automatically after the chillers to allow sufficient bloom time before the sides reach the graders. Performing this scribing cut before the chillers (through the bone only) would allow for accurate placement of this cut while removing the dangerous task of performing the break in the chiller. There are also improvements in tenderness which can be achieved (Tender Cut). Other scribing cuts along the spine which aren't determined by the grade of a given carcase can also be performed at the same time.

This project involved performing cutting trials at a processor site and assessing (by use of cameras) the amount of carcase movement experienced during, and after the performing of scribe cuts on a hot carcase. This will allow a complete picture of the requirements for carcase stabilisation.

3.1 Project Methodology

The project methodology of the Beef Anti-Sway Concept and Trial Study was:

1) Design conceptualisation of trial assembly to allow for assessment of hot beef carcase movement during and after placement of cuts.
2) Design and build a trial setup to support hot beef carcase sides and allow an operator to place desired scribe lines.
3) Selection and procurement of sensing equipment and mounting hardware (e.g. cameras) to enable motion to be observed and measured.
4) Organise trial at a processor site ensuring they are running hot beef carcase sides through the system. Report on results and learning

4.0 Methodology

4.1 Concept Design

The first stage was the concept design, coming up with a general design of a system which consisted of a manually actuated backing board frame that could extend out to a wide range of angles in order to support the carcase. Also, the design of a frame/stand consisting of mounting points for sensing equipment. Finally, selection of a sensing equipment to capture the carcase movement after each cut cycle.

4.1.1 Carcase Backing Board

The backing board frame design would need to accommodate the various sizes and weights that beef carcase sides could present with. The backing board would also need to swing out to a wide range of angles with some modularity there to allow for adjustability. The modularity would give us the opportunity to test stability at different angles.

4.1.2 Sensor Stand

The sensor mount stand would need to accommodate both lighting fixtures and camera mounting points. To keep it simple, off the shelf options could be implemented. For the scope of this trial, a simple tripod stand was selected based on our sensing equipment selection.

4.1.3 Sensor Equipment

The sensing equipment would need to detect any movement in the beef carcase side whilst the scribing cuts are being carried out. The main factors for consideration during camera selection will be the maximum and minimum carcase dimensions, lighting requirements as well as the field of view (distance away from the carcase).

4.2 Mechanical Design

Throughout the design conceptualisation phase, a list of design constraints as well as testing outcomes was developed and considered. These factors drove the final concept to ensure our design would meet the test criteria and answer any unknown variables.

4.2.1 Design Constraints and Variables

The primary design constraints considered were:

- Trial rig dimensions – Accommodate various carcase sizes and able to fit inside test site chiller rooms.
- Modularity – Easy to disassemble and adjust locations of various actuators/conveyors for ease of optimisation.
- Weight – Design must accommodate a range of carcase weights. Components to be selected accordingly.
- Material selection – Contact surfaces with the carcase must be food safe and able to be cleaned. Consider washdown environment during component selection.

- Safety – Operator safety is an important design consideration which needs to be accounted for. Operator will be carrying out cuts on an elevated platform whilst using a circular saw. He will need to be secured in a safe manner.

Some of the unknowns which need to be answered through these trials include: -

- Backing board
  - What backing board angle allows us to achieve optimal support on the carcase?
  - What is the impact of the support surface to carcase stability?
- Cutting Trial
  - How much movement will be induced on the carcase during a cut action?
  - Is there any effect regarding how the cut is approached?

4.2.2 Trial Rig Design

Considering the constraints and test variables, the below design was developed using 3D CAD.

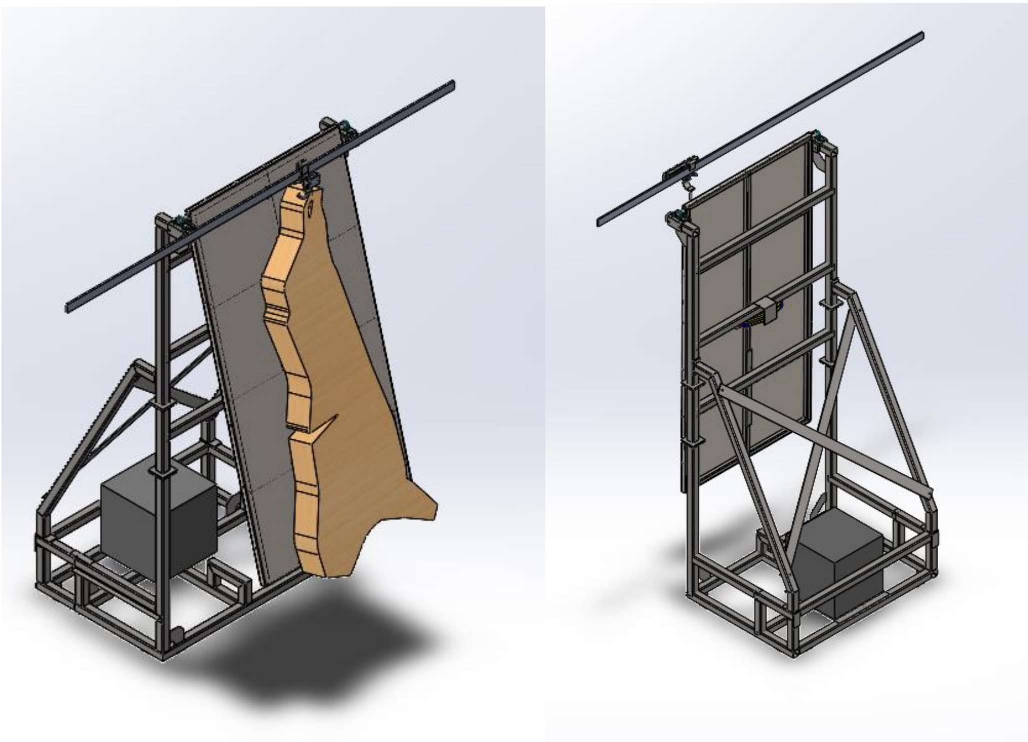

Figure 2: Manually Actuated Backing Board Assembly

In order to make the system modular and compact, the frame assembly was designed to easily disassemble and bolt together when inside the chiller room to allow for different room entry sizes during site evaluations.

For our saw selection, in order to ensure compatibility with existing services present in the chiller room and allow for ease of use for the operator, our trial site provided us with the saw and blades. The additional benefit of using a saw provided by site would mean the necessary safe working procedures and equipment validations have already been completed. Operators would also be familiar with the standard operating procedures for the saw used.

4.3 Trial Assembly Manufacturing

Leading on from the design conceptualisation, the next stage involved manufacture and assembly of our trial frame. The backing board and backing board frame assembly was fabricated using welded stainless-steel sections and folded/laser cut sheet. The main driver for this decision was the environment these assemblies would be going into (corrosive) as well as the fact that food will be in direct contact with the surfaces of the backing board.

In accordance with our design constraints, the backing board frame was manufactured in separate bolt on sections to allow access through doorways on site. The backing board design also allowed for manual indexing to different angles. The first step that had to occur, was the manufacturing of the trial assembly. This comprised of a range of modules which was assembled to make up the finished assembly.

4.3.1 Carcase Stabilisation

In addition to the trial frame assembly, we also manufactured varying stabilisation surfaces using 1mx1m section textured plastic (food contact safe) to explore their impact on carcase stabilisation during cutting.

4.3.2 Vision Calibration Board Case

A calibration board protective case was manufactured which would allow the operator to quickly cover our calibration board using a Perspex cover before carrying out scribe cuts, thus, protecting it from any bone dust and blood splatter.

4.4 Factory Trials

After assembly and setup was completed in the factory, we were able to move into factory acceptance trials. Leading on from our concept in milestone two, there were some critical design constraints which our manufactured trial assembly needed to achieve. Once assembled, we were able to test the following: -

- **Trial rig dimensions** – Accommodate various carcase sizes and able to fit inside test site chiller rooms.
    - We cross referenced actual measurements to the site layout and carcase dimensions provided by our trial site.
- **Modularity** – Easy to disassemble and adjust locations of various actuators/conveyors for ease of optimisation. The backing board needs to be adjustable to different angles.
    - The trial rig was designed to bolt together, this was tested during the assembly process on site.
- **Weight** – Design must accommodate a range of carcase weights. Components to be selected accordingly.
    - All components were selected to sustain the expected loads with a factor of safety taken into account. Any risk of tipping was eliminated by placing a 500kg concrete block at the rear of the assembly.
- **Material selection** – Contact surfaces with the carcase must be food safe and able to be cleaned. Consider washdown environment during component selection.
    - Full stainless-steel construction for all contact surfaces. Any sensitive equipment was made detachable to allow for storage in a different location.
- **Safety** – Operator safety is an important design consideration which needs to be accounted for. Operator will be carrying out cuts on an elevated platform whilst using a circular saw. The operator will need to be secured in a safe manner.

- Safety steps and platforms will be used instead of ladders. The manual backing board actuation mechanism has an additional safeguard with the indexing support bars to prefect the backing board from impacting the operator.

4.5 Site Trial Plan and Methodology

Due to the limited time we had allocated by site to conduct the trials, it was critical to develop a test plan and methodology in order to capture our required data and meet the milestone deliverables. The main goal of this phase of the project was to perform tests whereby hot beef sides are supported (i.e. by a backing board) while scribing cuts are performed on it. The amount of movement experienced during, and after placement of cuts will then be observed and assessed using an array of cameras and vision software to gain accurate values.

In order to make the most out of the time we were given for these trials, it was decided to prioritise a small sample set of trials from each of our different configurations for the first few days and then later move on to more focused trials using the configurations which worked best for us.

The trial plan allowed us to assess the unknowns and helped us decide what was critical for us to understand to meet the deliverables of this milestone. Once the schedule and test configurations were determined, a test methodology for each phase of the trial was developed.

4.6 Site Installation

The site installation of our trial rig was the first phase of our trials. Due to the short time frame we had to complete our trials, we chose to complete this over the weekend prior to trial start date. The installation involved assembly of the backing board frame and manual actuating mechanism, along with the safety indexing bars. Once assembled, the test rig was tested to ensure it can actuate at various angles for our test configurations.

4.7 Trial Results & Learnings

Once the trial rig was assembled and in position, the auxiliary components necessary for the trials could be placed in position as outlined by our procedures.

The carcase displacement before and after the cut were variables that we could quantify within a small margin of error, however, there were aspects of this trial which relied heavily on the qualitative assessment of the operator carrying out the cuts. Hence, we worked to keep the same operator throughout the cutting trials and noted his feedback on carcase response during each of the cuts and especially when the configurations were changed.

It was critical for us to take advantage of the fact that these cutting trials were being conducted by an experienced operator rather than a robot. This allowed us to direct feedback on how the carcase reacts to different cut paths and configuration changes throughout the trial. The learning gathered area good first step to understanding what we need to account for with the robotic cutting trials down the track.

4.7.1 Vision Analysis – Carcase Displacement

The purpose of the trial is to get an idea of how much the carcass will move between scribing cuts. To do this we will be using two cameras to collect video and still image data. The video camera will be looking at the profile of the carcass and will be providing us with qualitative data on how the carcass moved during the cutting process.

The photo camera will be positioned directly in front of the carcass to capture high resolution before and after images of the carcass and a calibration plate. The calibration along with depth measurements will allow us to make accurate measurements of carcass motion between cuts.

There were multiple stages of image processing involved to determine the carcase displacement throughout each of our cut phases. These stages are as outlined below:

- **Camera Calibration**

  Camera calibration was required to remove common forms of lens distortion from the image. The image below demonstrates the differences between the original image (left) and an undistorted image (right). In the original image, straight lines appear curved dues to the lens distortion, whereas in the undistorted the same lines.

Figure 3: Original and Undistorted Images

- **Calibration Accuracy**

  Using the camera calibration parameters and geometry of a calibration board, the pose of the calibration board can be estimated in each image. This in turn allows us to calculate the 3D coordinates of every checkerboard corner. These calculated 3D coordinates can then be projected back into the image to see how close the projection is to the true checkerboard corners on the image.

- **Image Rectification**

  Image rectification is the process of wrapping an image to remove perspective distortion. For example, due to the position of the camera, the rectangular calibration board will appear trapezoidal. Thus, using the known geometry of the calibration board and its calculated position, a homography transform is calculated to remap the image so that the board appears rectangular.

Additionally, the resolution of the remapped image can be set so that, for example, each pixel in the rectified image represents 0.1 mm in the real world. The rectification procedure described above allows us to make accurate measurements of features that lie in the same plane as the calibration board. This homography calculation is dependent on the pose of the calibration board, therefore by altering the estimated pose, we can rectify the image into any plane in the real world.

- **Post Processing**

  In this trial we are interested in measuring how much the carcass moves after the first cut and second cuts (the 5-6 and grading site spine cuts). Specifically, after the 5-6 cut we need to measure how much the carcass moves around the grading cut region. Furthermore, after the grading cut, we need to measure how much the carcass moves around the lumbosacral region. Therefore, to make these measurements, all images are rectified twice so that accurate measurements can be made at the grading and lumbosacral regions.

- **Measurement of Displacement**

  In order to calculate how much a feature moves between cuts, we can simply look at the rectified before and after images and compare the pixel position of distinctive features.

4.7.2 Vision Analysis – Results

During the initial stages of the trial, cuts were performed at all backing board configurations to identify the best configurations so that we can focus on the best configuration for the remainder of the trial, using the feedback from the saw operator, video data and movement measurements.

4.8 Design Considerations

Throughout the course of these trials, we were able to assess the feasibility of carrying out scribe cuts on a hot carcase. We were able to look at what cuts can and can’t be made, as well as the various stabilisation and cutting considerations which need to be considered. Below is a list of our critical design considerations after observing the carcase movement at the various backing board configurations.

- **Backing Board Location**

  The location of our backing board relative to the top rail was a variable which impacted directly on the amount of support and tension (due to the hook stretch) we were placing on the carcase during the cut phases.

  As we move the primary position of the frame further away or closer to the rail assembly altered the contact between the top half of the carcase and backing board. Increasing the distance would result in less pressure due to the weight of the carcase on the backing board as we push out to the various angles, whereas reducing the distance would result in an increase in surface contact between both the rump and chest section of the carcase.

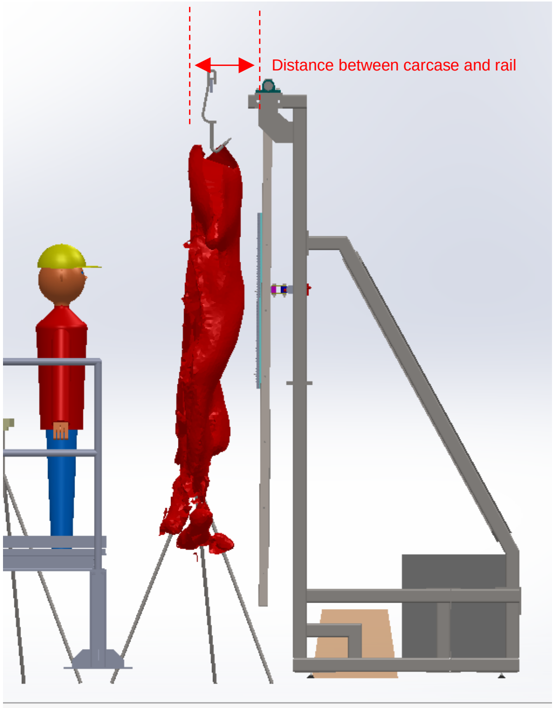

Figure 4: Distance Between Rail & Carcase

- **Backing Board Angle**

  The backing board angle aw a significant design consideration as it had an impact on carcase movement both during and after each of the cut phases. One variable that is difficult to assess quantitatively is the carcase movement as the operator is carrying out each cut operation. This data was analysed qualitatively by examining the videos of each cut phase and then determining our optimal backing board angle.

- **Carcase Stabilising Mechanism**

  Due to the excess movement on the carcase during and after cut phases, we needed to consider the amount of carcase displacement and how this can impact our cut accuracy. Due to the amount of displacement observed without the use of any stabilising mechanism, we would need to consider various options to ensure the carcase stays fixed in position during the cut phase (i.e. using a textured stabilising surface etc.). This stabilising mechanisms would need to work together with our optimal backing board angle to maximise our carcase support during and after a cut.

- **Saw Cut Path Variations**

  The operators' angle of approach to the carcase would be another design consideration which would impact the carcase displacement. If we are pressing into the carcase at an angle which is not optimal for clearing through the carcase, there is a higher likelihood of the carcase being pushed laterally along with the saw. Thus, inducing a significant displacement on the carcase relative to its original position.

5.0 Conclusions / Recommendations

This stage of the project was completed on budget, and within schedule. The rig was fully manufactured and installed on site within this milestone, and the trials were also completed successfully. As a result, our results can be assessed and a report on our findings could be developed.

The core objective of this project was to perform cutting trials on hot beef carcase sides to accurately assess the amount of movement experienced during and after the placement of our scribing cuts (using vision). Various carcase supporting techniques would also be explored to determine the feasibility and effectiveness of our chosen designs. We were able to achieve this objective through the course of the trials to determine the optimal carcase support method whilst highlighting causes for the instability during cut operations. We were also able to determine the optimal cutting technique to ensure we minimise the deviation in the carcase during the cuts.

By analysing the trial results to assess the feasibility of hot scribing we were able to determine what design considerations were critical to reducing the magnitude of displacement we see on the carcase. We were also able to use operator feedback to determine what cutting considerations need to be made in order to achieve the best result with minimal pressure on the carcase. These results showed us that the need for a carcase stabilisation mechanism would be critical to achieving the ROI goals for the customer by increasing the accuracy of our cuts.

The next steps in the wider scope of our project goals will be to take these learning and transfer them to a robotic cutting application so that we can mimic the operators' techniques whilst ensuring we target the root causes of carcase instability using supporting mechanisms.