Final report

AUSTRALIAN MEAT PROCESSOR CORPORATION

Waterless Lamb Frenching Prototype

2024-1020 Waterless Lamb Frenching Prototype

Project code
2024-1020

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1.0 Executive summary

The purpose of this research project was to develop an automated waterless frenching solution as a safe and sustainable alternative to frenching with water or knives. This project built on the findings of the Alpha prototype that was produced under project 2023-1020. The overarching objective of the project was to demonstrate that the automated solution was commercially viable by producing a repeatably high standard of frenching at sufficient speed to meet production requirements.

A Beta prototype was produced that incorporated the recommended design improvements of the Alpha prototype while also meeting food hygiene and machine safety standards. Significant testing and development of the Beta prototype was conducted with the most successful test achieving an 86% repeatability rate over a trial of 50 lamb racks. Unfortunately, this is too low to be commercially viable and further development is required. The key issue that reduced the repeatability rate was the inability to position the bones at the very high level of accuracy required. Throughout the project significant improvements were made in this area however there are still some instances where the performance is insufficient which results in damage occurring to the lamb rack bones. Based on this, it is unlikely that the current approach could be developed to a commercially viable level.

Future research should focus on developing an approach that does not require as accurate bone positioning. This could be implemented within the structure of the existing Beta prototype to make use of those sub-systems that performed well during the trials.

2.0 Introduction

The purpose of this research project was to develop an automated waterless frenching solution as a safe and sustainable alternative to frenching with water or knives. In Australia, most processing facilities rely on operational staff with knives to undertake this activity. There are instances in Australian plants using the McLaren Stainless water frenching solution. Although this solution works well it is not suitable for all Australian locations due to the water usage, water source, and resulting additional trade waste load with the product (intercostals) and water being discharged to drain. Each 8-rib rack requires at least 21 knife actions (and up to 23), this activity results in up to 210,000 knife actions per operational staff member within a plant operating at 10 carcases per minute. This task has both a WHS repetitive strain and knife laceration safety concern.

Under the previously completed project 2023-1020, Curious Creations Ltd was supported by AMPC to produce an Alpha prototype to test the waterless automated frenching method that Curious Creations Ltd had conceptualised. The Alpha prototype demonstrated that the prototype had potential to be commercially viable; however some design development was required to improve the repeatability of the process. Project 2024-1020 was then initiated to produce a Beta prototype that would incorporate the design improvements identified from the Alpha prototype, while also incorporating food hygiene and machine safety design elements to enable larger scale testing.

3.0 Project objectives

The following project objectives were agreed between AMPC and Curious Creations Ltd:

- Design and produce a Beta Prototype that incorporates the design change recommendations of the Alpha prototype, and complies with relevant industry food hygiene and safety standards including:
    - ISO 14159:2002 Safety of Machinery – Hygiene Requirements for the Design of Machinery
    - Relevant areas of the AS/NZS 4024:2019 Safety of Machinery Series

- Design and produce a Beta Prototype that is easy to install, operate, maintain and clean with:
    - Design features that enable replacement of the cutting wires in under 5 minutes.
    - Design features that enable replacement of the cutting blades in under 10 minutes.
    - Easy access to all areas that come in contact with product for cleaning.

- Design and produce a Beta Prototype that has design features that enable an adjustable frenching length between 40mm and 70mm, and the processing of lamb racks with a bone/cap thickness of 6mm to 20mm.

- Carry out Beta Prototype trials to validate that a production system will be a commercially viable alternative to manual frenching by:
    - Confirming that a single Beta Prototype can achieve a throughput of 2 racks/min, while taking up less floor space than manual frenching methods.
    - Confirming that the Beta Prototype is simple to operate, and multiple Beta Prototypes could be operated as a production system by a single operator in a production setting.
    - Confirming that the anticipated labour savings of a production system will offset the operating cost of a production system.
    - Confirming that the Beta Prototype can produce lamb racks of multiple specifications including the common industry standards of:
        - 8 rib cap-off lamb rack, 100mm, 50mm French
        - 8 rib cap-off lamb rack, 75mm, 37mm French
        - 8 rib cap-on lamb rack, 75mm, 37mm French

- Carry out Beta Prototype trials to test and validate the repeatability of the process, with the objective of:
    - The Beta Prototype producing a better frenching finish than is achieved by manual frenching on 90% of the samples trialled over a trial of at least 50 samples.
    - The Beta Prototype achieving a frenching length within 5mm of the desired frenching length between 40mm and 70mm.

4.0 Methodology

The project was completed in three major phases including Design, Construction, and Testing and Development.

Design

The Beta prototype design was produced using computer aided design (CAD) tools. Initially a basic model was developed which provided an overview of how the Beta prototype would operate. Following this, the design was presented to representatives of the meat processing industry to gain their input for the design of the Beta prototype. There were no major changes requested by the industry representatives, and the detailed design was able to commence.

The detailed design of the Beta prototype was then produced. This involved incorporating the requirements from the machine safety and food hygiene design standards, while also incorporating design features to improve the repeatability of the system when compared to the Alpha prototype. Key components such as pneumatic actuators were selected during this process and the required system architecture was designed to incorporate them within the prototype. Multiple design iterations were completed to eventually arrive at a design that was believed to be capable of achieving the project objectives.

Production drawings and specifications were then produced for those components that needed to be manufactured. Suppliers for these components were identified and engaged to gain quotations. During this stage, the components were optimised for ease of manufacture to ensure that the Beta prototype could be produced within the project budget. Where appropriate, some components were reused from the Alpha prototype to reduce cost. A parts list was then developed for the Beta prototype so that the delivery of components could be tracked to ensure the project remained on schedule.

Construction

The assembly of the prototype was completed as the required components arrived from the various suppliers. This enabled the sub-assemblies to be constructed and tested to verify the fit and performance before being assembled into the complete system. Once all of the components had arrived the complete mechanical assembly of the prototype could be completed. The electrical wiring and pneumatic plumbing was then completed to connect the various actuators, sensors and switches with the control devices. The initial control software was then produced, tested and developed to confirm the correct operation of the prototype.

Testing and Development

Multiple phases of testing and development were conducted during this project. Initially, tests were carried out with 3D printed models that represented the lamb rack bone structure. This enabled the bone sensing and positioning system to be tested and developed in isolation from the cutting and stripping mechanism. The 3D printed models had the benefit of enabling these systems to be extensively tested without the cost associated with procuring lamb racks. Figure 1 displays an example of the 3D printed models.

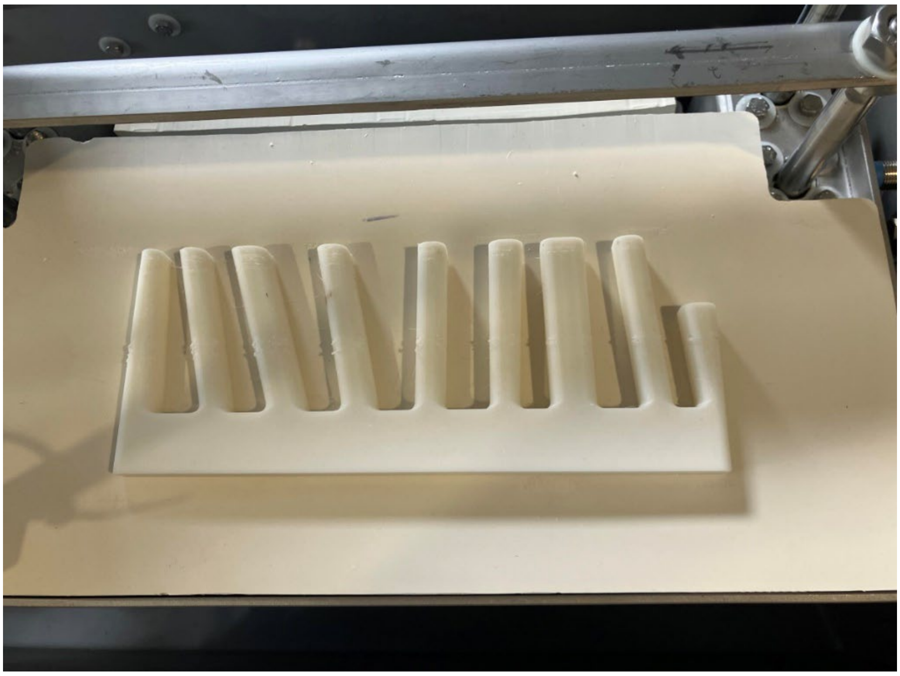

Figure 1: 3D printed lamb rack bone structure used for initial positioning testing.

Once the bone sensing and positioning system was tested to a satisfactory state, testing could commence on the cutting and stripping mechanism. Un-frenched lamb rack samples were procured in small quantities and multiple testing sessions were carried out with adjustments to the prototype made between. In total, 7 testing sessions of 4-8 lamb racks were completed with improvements made between each session. Adjustments made to the prototype included; pressure settings of the various actuators, minor hardware changes, configuration of the cutting wires, and changes to the bone sensing and positioning algorithms within the software that operated the prototype. Eventually there was sufficient confidence in the performance of the prototype to conduct the first large scale test.

For the first large scale test, 50 lamb racks were procured from the local meat processing facility and were provided in a Cap-Off, 100mm bone length specification. A continuous trial was completed in a workshop environment to test the repeatability of the system with the prototype set to provide a 50mm frenching length. During the test, various data sets were captured for each of the lamb racks including; images of the resulting lamb racks, video footage of the testing (only some tests), and output data from the bone positioning system. The various data sets were reviewed upon completion of the test to determine the success rate of the prototype, and to identify areas for improvement.

As discussed in Section 5, there were some repeatability issues encountered during the initial 50 rack test. To attempt to rectify this, design changes to both the hardware and software were then developed and implemented. These updates pertained to the bone sensing and positioning sub-systems with changes made to the carriage, tip sensor, and processing algorithms. These updates were intended to better secure the lamb racks within the carriage, and provide a more accurate measurement of the bone tip profile and location.

A second large scale test was then conducted with another 50 lamb racks. For this test 25 of the racks had a bone length of 100mm and were frenched to 50mm, and 25 of the racks had a bone length of 75mm and were frenched to 37mm. Once again, various data sets were captured for each of the lamb racks including; images of the resulting lamb racks, video footage of the testing (only some tests), and output data from the bone positioning system. The various data sets were reviewed upon completion of the test to determine the success rate of the prototype, and to identify areas for improvement.

5.0 Project outcomes

The project outcomes have been defined against the project objectives listed in Section 3.

Objective 1:

Design and produce a Beta Prototype that incorporates the design change recommendations of the Alpha prototype, and complies with relevant industry food hygiene and safety standards including:

- *ISO 14159:2002 Safety of Machinery – Hygiene Requirements for the Design of Machinery*
- *Relevant areas of the AS/NZS 4024:2019 Safety of Machinery Series*

The completed Beta prototype is displayed in Figures 2, 3, 4 and 5 and was designed to incorporate the recommended improvements identified during testing of the Alpha prototype. Specifically, the Beta prototype has incorporated:

- Dual bone position sensors so that the angle of the rib bones can be measured and accounted for during the cutting and stripping process.
- An additional mechanism to remove the intercostal meat from the cutting wires after the stripping process so that intercostal meat doesn't accumulate on the wires.
- Increased actuation force on the cutting blades and thicker cutting blades.
- Incorporation of a carriage rather than the conveyor design used in the Alpha prototype to improve bone positioning accuracy.

Figure 2: Overview of assembled Beta prototype

Figure 4: Beta prototype carriage

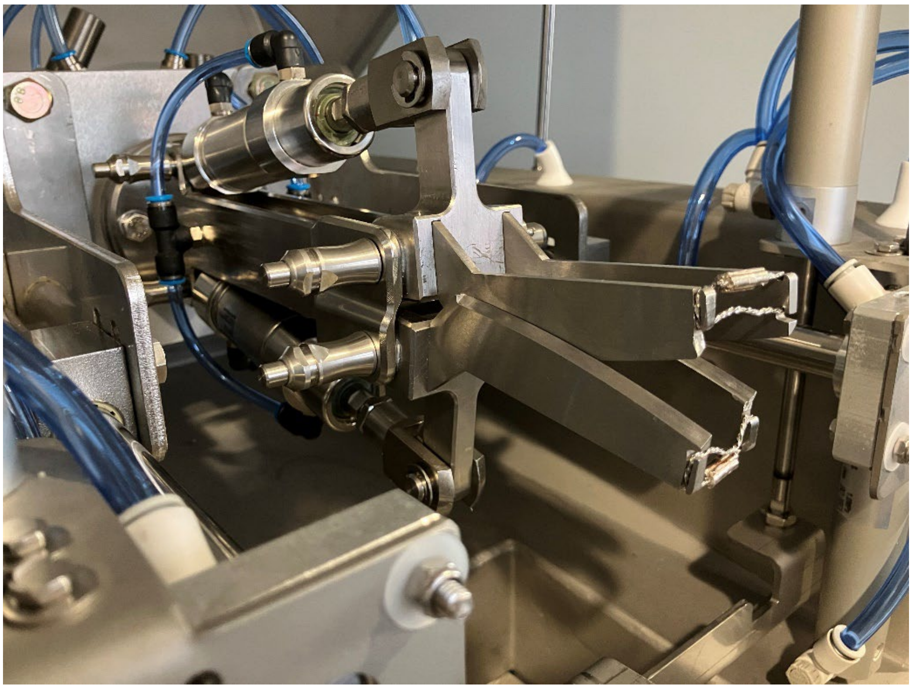

Figure 3: Beta prototype cutting head

The Beta prototype has also been designed to comply with the AS/NZS 4024 machine safety standard, and the ISO 14159 food hygiene standard. Specifically, the Beta prototype includes:

- An enclosed design with interlocked doors to prevent access to the hazardous areas of the machine when operating.
- Low voltage electrical components.

- Waterproof electronics in areas that may get wet during washdown.
- Stainless steel components used in the majority of areas that come into contact with product and cleaning chemicals. In some areas, aluminium pneumatic actuators have been utilised instead of stainless steel actuators to reduce cost until the size is confirmed through testing. These can be directly replaced with stainless steel variants in future.
- Self-draining design to ease cleaning.
- Easily removable components in areas that contact the lamb racks including the, cutting blades, cutting wires, rubber carriage base mat, rubber carriage tip clamp.

Objective 2:

Design and produce a Beta Prototype that is easy to install, operate, maintain and clean with:

- *Design features that enable replacement of the cutting wires in under 5 minutes.*
- *Design features that enable replacement of the cutting blades in under 10 minutes.*
- *Easy access to all areas that come in contact with product for cleaning.*

Figures 5 and 6 display the process that is completed to remove the cutting wires and blades. The cutting wires can be removed and reinstalled by flexing the blades together and sliding the wires out of the machined grooves in the cutting blades. Alternatively, the wires can also be removed by cutting them, this may be more appropriate in a production setting as the wires are intended to be an expendable item. The cutting blades are removed by removing the quick release indent pins and sliding the blades out of the housing. These design features enable the blades and wires to be quickly replaced in under 5 minutes.

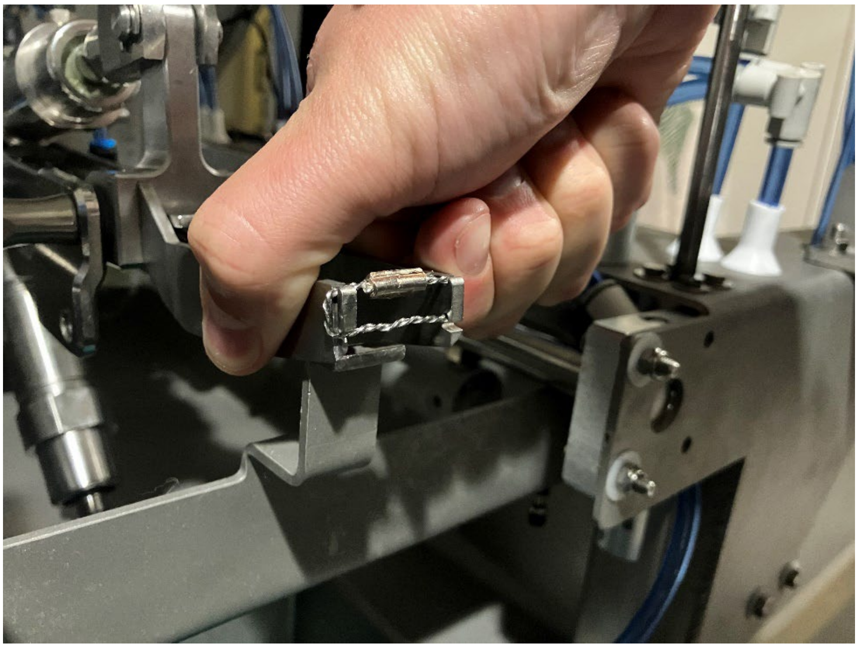

Figure 5: Cutting wire removal process

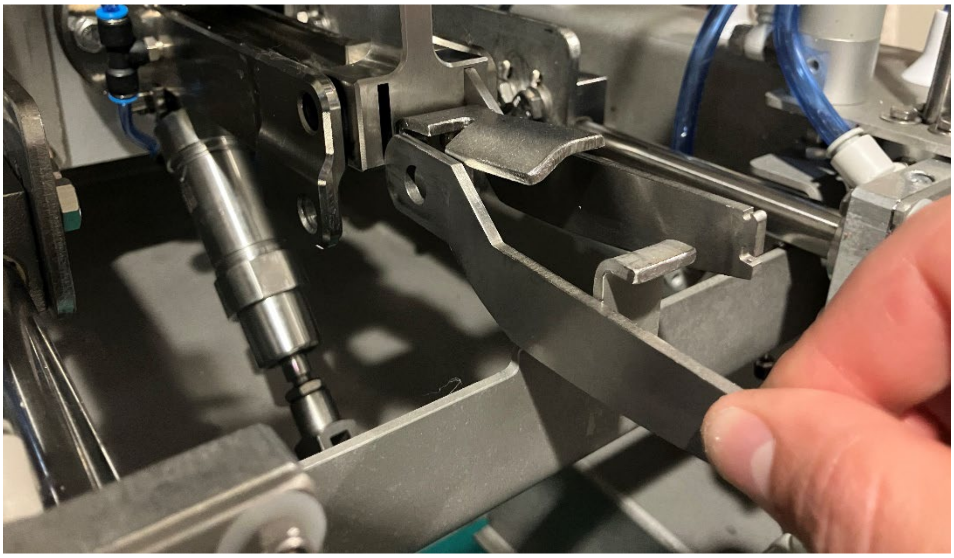

Figure 6: Blade removal process

Objective 3:

- *Design and produce a Beta Prototype that has design features that enable an adjustable frenching length between 40mm and 70mm, and the processing of lamb racks with a bone/cap thickness of 6mm to 20mm.*

The frenching length on the Beta prototype is adjusted through the backstop displayed in Figure 7. The lamb racks are placed in the carriage so that the tips of the bones are touching the back stop. The position of the back stop is adjusted by loosening the two bolts that secure it, and sliding the back stop within the machined slots. The frenching length is measured from the position of the back stop to the edge of the carriage. A production version of the prototype could include an electronically adjusted back stop so that the frenching length could be adjusted through the user interface.

Figure 7: Frenching length adjustment backstop

The clamping mechanism on the carriage has a maximum opening of 25mm. This allows a variety of bone thicknesses to be clamped, and also allows for longer frenching lengths where the rack is clamped higher up the length of the bones.

Objective 4:

- *Carry out Beta Prototype trials to validate that a production system will be a commercially viable alternative to manual frenching by:*
  - *Confirming that a single Beta Prototype can achieve a throughput of 2 racks/min, while taking up less floor space than manual frenching methods.*
  - *Confirming that the Beta Prototype is simple to operate, and multiple Beta Prototypes could be operated as a production system by a single operator in a production setting.*
  - *Confirming that the anticipated labour savings of a production system will offset the operating cost of a production system.*
  - *Confirming that the Beta Prototype can produce lamb racks of multiple specifications including the common industry standards of:*
    - *8 rib cap-off lamb rack, 100mm, 50mm French*
    - *8 rib cap-off lamb rack, 75mm, 37mm French*
    - *8 rib cap-on lamb rack, 75mm, 37mm French*

Prototype Speed: With the Beta prototype set to maximum speed, a cycle time of 28 seconds was achieved. This does not include the time taken by the operator to replace the lamb rack at the end of the process. It is estimated that an experienced operator in a production setting could complete this task in 5 seconds, which would give a total cycle time of 33 seconds. This is slightly higher than the project objective of 2 racks/min or 30 seconds per cycle. If required, the cycle time could be slightly reduced by implementing a higher power drive motor to the carriage system which would enable the carriage to return faster after the frenching process is completed.

Operation Process: The Beta prototype is simple to operate with the process consisting of; opening the access door, removing the frenched lamb rack from the carriage, installing a new lamb rack, closing the door and pressing the start button. A production system should consider a means of automatically ejecting the frenched lamb racks from the carriage as this would reduce the loading time. Allowing a loading time of 5 seconds, a person could operate up to 5 modules which would enable 10 racks to be frenched in 66 seconds or 9.1 racks per minute. This would require the modules to be packaged closely together so that each of the loading points are within reach of the operator. This could be achieved by mounting the modules vertically as displayed in Figure 8. Depending on the number of modules required, and the floor space, these could be arranged around the operator to reduce the loading effort.

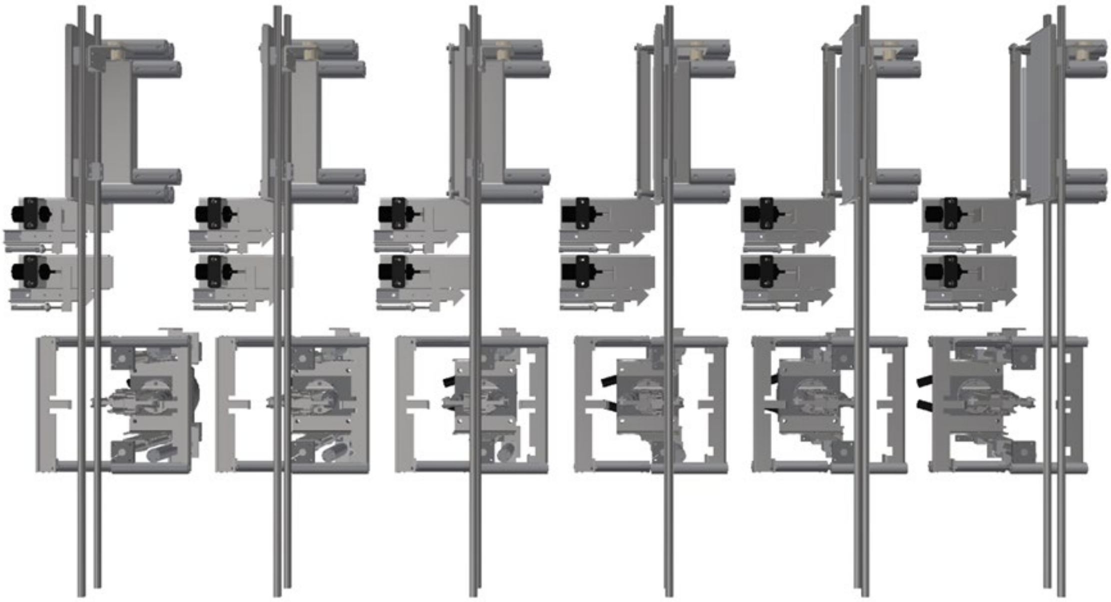

Figure 8: Intended configuration of multiple module installation to minimise floor space.

Operation Cost: The primary operating cost of a production system would consist of electricity to drive the machine and an air compressor as well as component consumables and maintenance. The operating cost of a 5 module system per single 10 hour shift has been approximated in table 1. These values have been estimated based on the performance of the Beta prototype. Further discussion comparing the operating cost to the potential labour savings is included in Section 6.

Table 1: 5 module production installation estimated operating cost

Item	**Usage Per Day**	**Unit Cost ($)**	**Cost per shift ($)**
Electricity (Air compressor and frenching machine)	150kWh	0.20/kWh	30.00
Cutting Wires (assume each wire lasts one shift)	5 sets	10.00	50.00
Maintenance	-	-	100.00
Total			180.00

Product Specification: The Beta prototype was tested across a range of frenching lengths to verify that it is capable of producing multiple specifications of lamb racks. With the current clamping design, a minimum of 35mm of the bone length was required to clamp the lamb racks. This enabled a 100mm bone length rack to be frenched up to 65mm, and a 75mm bone length rack to be frenched up to 40mm. This allows most common specifications of racks to be achieved, however longer frenching lengths or racks that are fully frenched would require a different clamping design.

An objective of the project was to trial the processing of cap-on racks however this was not achieved due to the repeatability challenges that were encountered when processing cap-off racks. As cap-off racks are a more common specification, these were the focus of the trial and introducing another variable of attempting cap-on racks would not have been productive towards achieving the overall project goals.

Objective 5:

- *Carry out Beta Prototype trials to test and validate the repeatability of the process, with the objective of:*
    - *The Beta Prototype producing a better frenching finish than is achieved by manual frenching on 90% of the samples trialled over a trial of at least 50 samples.*
    - *The Beta Prototype achieving a frenching length within 5mm of the desired frenching length between 40mm and 70mm.*

To determine a baseline quality standard for the frenching process, photos of hand frenched racks were sourced from a meat processor. These are displayed in Figures 9 and 10.

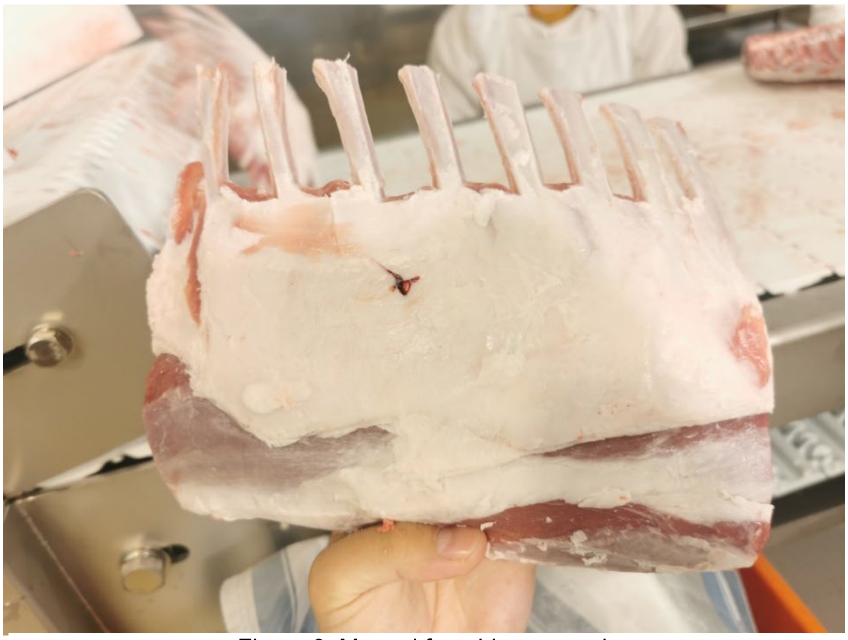

Figure 9: Manual frenching example

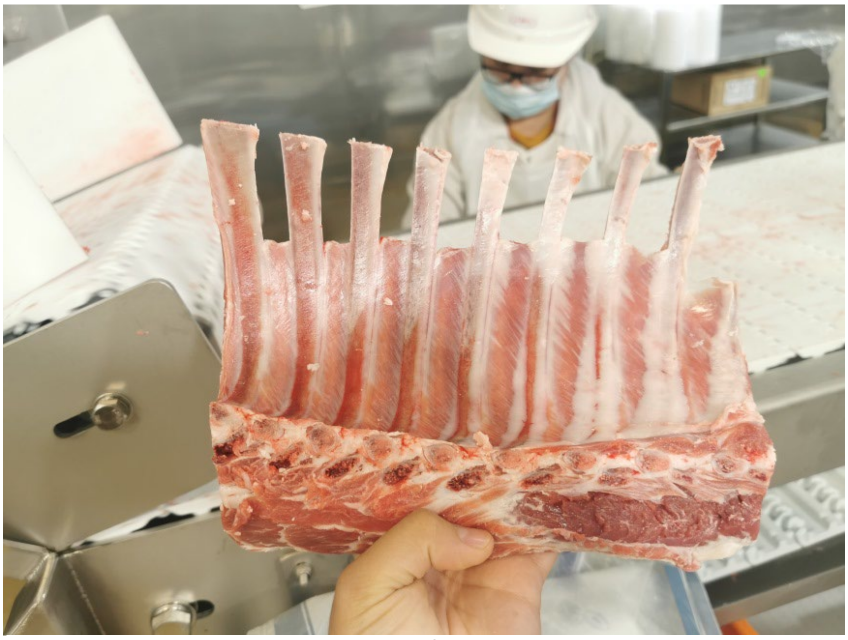

Figure 10: Manual frenching example

The first 50 rack test was conducted with racks that were provided in a 100mm cap off specification and the Beta prototype was setup to provide a 50mm frenching length. The results from the test are summarised in table 2 with the samples being graded into three categories.

Grade	Description of Grade	Number of samples in grade
A	Ideal result with minimal intercostal remaining, even frenching length and no bone damage.	14
B	Result is acceptable but small defects exist such as uneven frenching length, some intercostal remaining on bones, or small amount of chipping on tips of bones.	29
C	Bones have been broken and removed from the rack.	7

Figures 11 to 13 display a representative result for each of the grades in table 2.

Figure 11: Example of ideal grade 'A' test result

Figure 12: Example of grade 'B' test result with bone chipping and some intercostal remaining.

Figure 13: Example of grade 'C' test result with broken bones

Figure 14 displays the accumulation of removed intercostal meat within the removable tray at the end of the trial. The prototype was successfully removing the intercostal meat from the cutting wires and there was no damage present to the wires or cutting blades.

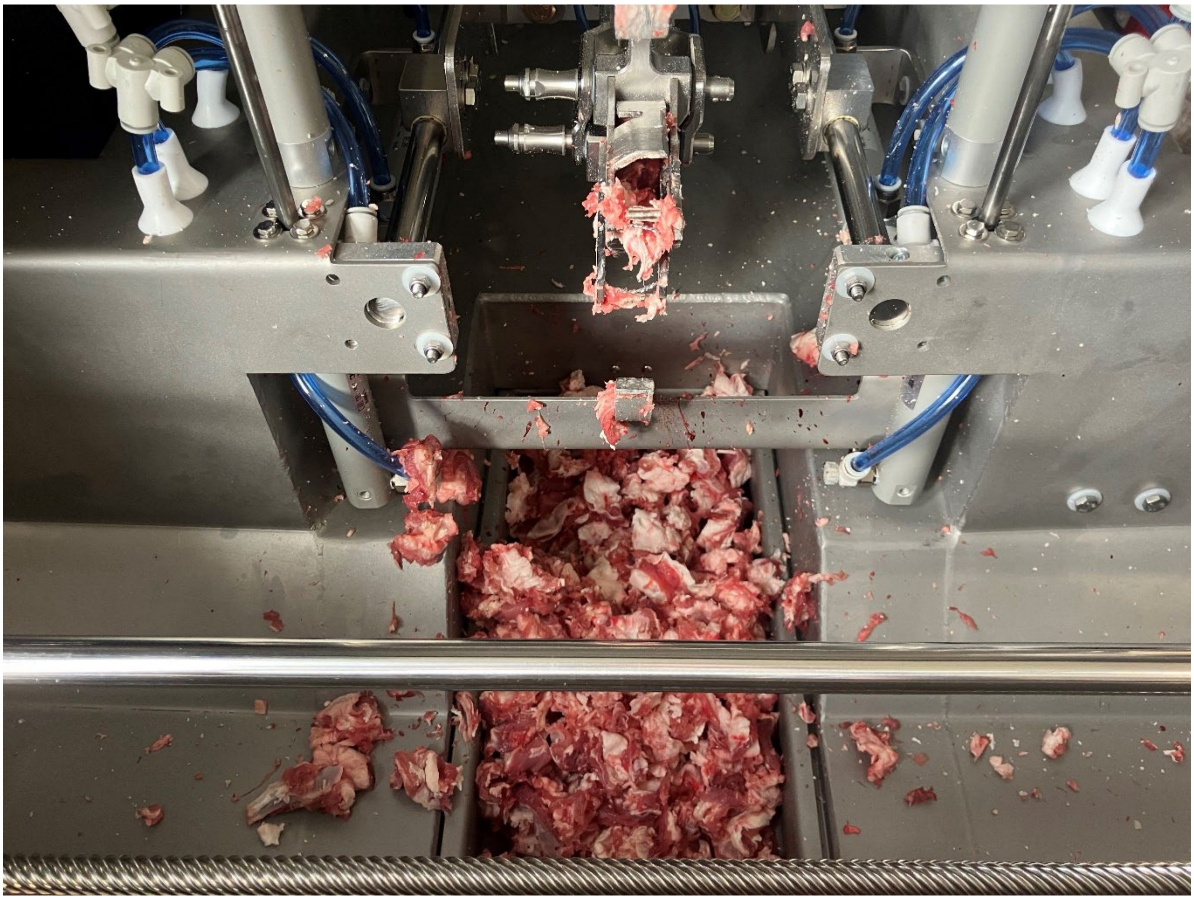

Figure 14: Accumulated intercostal post-trial

If it is accepted that the 'B' grade racks still represent an acceptable standard, then the trial achieved a repeatability rate of 86% (43 out of 50). If the 'B' grade racks are not acceptable, then the trial achieved a repeatability rate of 28% (14 out of 50).

The broken bones and bone chipping was caused by the cutting blades colliding with the bones during the cutting and stripping process. This was due to either the position of the tip of the bone not being accurately measured, or the bone moving after it was sensed. Often there is very little space between the tips of the bones as the bones tend to widen along their length. It is therefore critical that the cutting head is accurately aligned with the tips of the bones to prevent a collision occurring.

Bone Tip Position Accuracy: It is critical that the position of the tips of the bones is accurately measured so that the cutting head can be positioned within the gaps between the bones. The tip position sensor utilises a follower mechanism that measures the profile of the bones and then determines their position. It was not possible to position this follower mechanism on the exact tip of the bones for two reasons. Firstly, the cut line where the flap is removed from the racks is not always straight as displayed in Figure 15. Also, some of the racks have very thin bones which become flexible at the tip as displayed in Figure 16. In these instances, the tip sensor follower mechanism does not follow the profile of the bone due to the bone flexing downwards.

Figure 15: Cut line of rack bones is often not straight which requires the tip sensor to be offset from actual tip

Figure 16: Some rack bones are thin and flexible at the tip which prevents detection by the tip sensor follower mechanism.

The two factors highlighted in Figures 15 and 16 result in the tip sensor being positioned 10mm from the tip of the bones to give a repeatable reading. The position of the bone tip is then estimated by extrapolating the measured position of the bone tip and the bone base, and assuming that the bone angle remains constant. The diagram in Figure 17 displays the problem with this method. Often the angle of the bone does not remain constant which results in inaccuracy between the estimated tip position and the actual tip position. This can cause the cutting blades to collide with the edge of the bone tip in situations where there is only a small amount of clearance between the bones. In a best-case scenario, a small amount of bone is sliced off, but sometimes the bone is instead pushed forward in the clamp which misaligns other bones within the lamb rack.

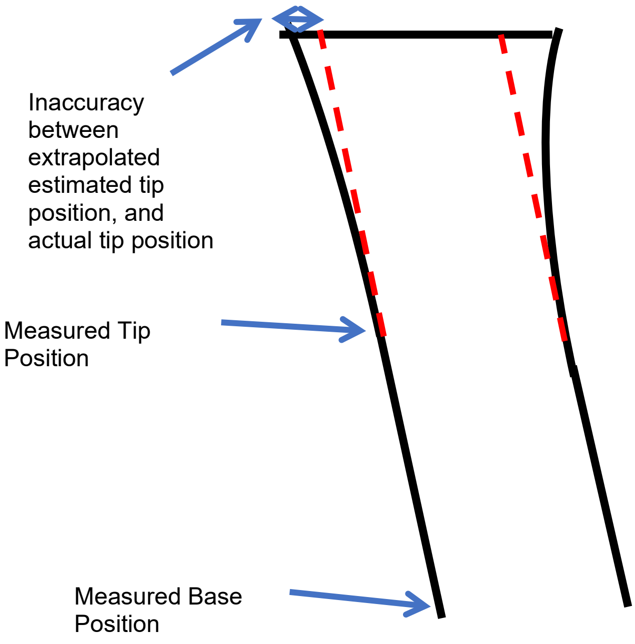

Figure 17: The inaccuracy resulting from extrapolating the tip position.

Bone Movement Post Sensing: The other significant problem that was encountered was bones moving during the cutting and stripping process. This scenario is displayed in the diagram in Figure 18. The movement of the carriage that occurs during the frenching process to align each bone can cause the cutting blades to collide with adjacent bones. This moves the adjacent bones from the position that they were sensed at which creates an error between the sensed position of the bones, and the actual position. This can then result in the cutting blades colliding with the edges of these bones during the frenching process.

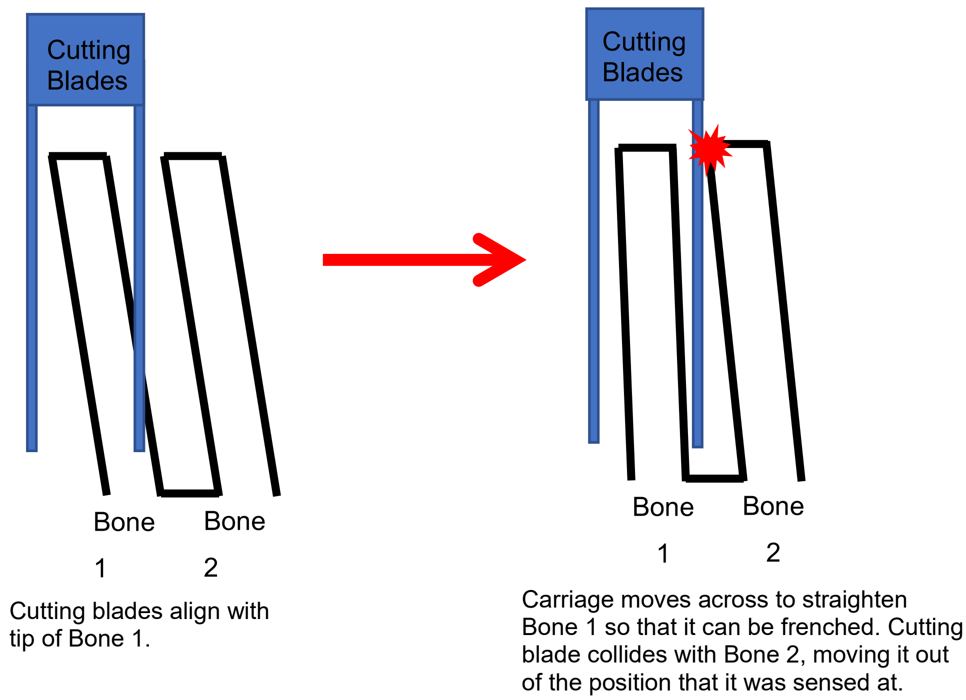

Figure 18: Bone position error caused by collision between the cutting blades and adjacent bones.

Second Trial

After completion of the first trial, design changes were made to the Beta Prototype to attempt to improve the repeatability rate. A new carriage was designed that better secured the rack bones to prevent movement. This was achieved through higher powered clamping actuators. Changes were also made to the control algorithms to minimise the movement of the carriage when straightening the rack bones.

50 lamb racks were sourced for the second trial with 25 having a 75mm bone length and the other 25 having a 100mm bone length. Unfortunately it soon became clear during the test that the design changes had not improved the performance of the Beta prototype. Although the new carriage design was significantly better at securing the rack bones, this resulted in excessive resistance to the bones straightening. Because of this, the angled bones would become entangled in the cutting blades and break as the cutting head rotated. The trial was stopped midway through, and the remaining test samples were preserved for future testing as it was clear that the repeatability rate was worse than the previous test.

6.0 Discussion

Repeatability

As detailed in Section 5, the best result achieved was a repeatability rate of 86% over a 50 rack trial. This was only slightly below the project objective of 90%, but significantly below a commercially viable level. At an 86% repeatability rate, the Beta prototype would damage approximately 15 lamb racks per hour when operating at the 33 second cycle time that was achieved. The lost value of the damaged lamb racks would far outweigh any labour saving that could be achieved. To be commercially viable, a repeatability rate much closer to 100% needs to be realised.

During this project significant testing and development was conducted to optimise the current approach. With the challenges described in section 5, it is unlikely that the existing approach could be improved to a commercially viable level of repeatability. A new approach to removing the intercostal meat should be developed that does not rely on very accurate positioning of the tips of the bones.

Durability

A common question that is often raised is the durability of the cutting wires. This is difficult to test without conducting production testing. One set of cutting wires were used for both tests which totalled 75 lamb racks and there was no damage present to the wires afterwards. At the target production speed of 2 racks per minute, each module could process up to 1200 lamb racks in a 10 hour shift. It is not yet clear if a set of cutting wires could last a full shift, however the initial results are promising. The sharpness of the cutting blades was also inspected after the testing with no noticeable difference. This is likely due to the relatively flat cutting angle of the blades that operate in a scissor configuration.

Operating Cost

The operating cost of a 5 module production prototype was estimated in Section 5 to be $180 per 10 hour shift. This is likely to be significantly less than the labour savings that could be achieved through the implementation of automated solution. Assuming that manual frenching is conducted at an average speed of 30 seconds per lamb rack, a 5 module production prototype could reduce the labour team by four, with only one person required to operate the 5 modules. Assuming a labour rate of $30 per hour, this would correspond to a labour saving of $1200 for a 10 hour shift.

7.0 Conclusions / recommendations

The purpose of this research project was to develop an automated waterless frenching solution as a safe and sustainable alternative to frenching with water or knives. A Beta prototype was produced and tested that was based on the automated frenching concept that was demonstrated with the Alpha prototype. Some challenges were encountered during the testing of the Beta prototype and a commercially viable repeatability level could not be achieved with the current approach. To improve the repeatability of the Beta prototype it is recommended that a new approach is developed that does not rely on accurate positioning of the lamb rack bone tips. If possible, this new approach should utilise the existing Beta prototype body, carriage, and bone sensing systems with a redesigned mechanism for removing the intercostal meat.