Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

Automated Beef Scribing

Automated Beef Scribing – Stage 2 (Intelligent Robotics)

Project Code
2021-1156

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Published by
AMPC

Date Submitted
14/03/2022

Date Published
14/03/2022

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1.0 Executive Summary

In a recent engagement AMPC with over 94% of Australia's beef processing throughput capacity, close to 100% of beef Australian beef processors identified beef scribing in their Top 20 or 100 areas of Innovation they want to adopt within the next 5 years within their business (assuming there is a fit for purpose solution for their business). To this end, AMPC issued an innovation challenge to researchers and commercial developers to work with AMPC and the industry to understand if we can improve on the current offering.

In approaching AMPC's innovation challenge through this project, Intelligent Robotics have developed a design for a beef scribing system to address the inspirations of the AMPC innovation challenge. In relating back to the objectives that were established for the project:

1. **Develop an automated scribing concept and assess its alignment with the following aspirations: Modular (applicable to a range of processing plants from an ROI perspective); Smaller footprint; Simpler installation; and Able to perform a number of cuts**

   The concept has been designed with these aspirations in mind as key design criteria. The concept consists of a number of variations and is able to be driven by different sensing modalities allowing these aspirations to be addressed while maintaining maximum coverage for the technology across the Australian red meat industry.

2. **Perform design and equipment selection tasks to provide accurate costing for the cell concept in terms of commercial price and cost of further development**

   The design of the concept was developed to a detailed enough level to enable accurate costings to be developed. The design for the different concepts were outlined in detailed, as well as the expected commercial $RRP for each concept, and a detailed outline of what the initial projects may look like in terms of costing and structure.

3. **Detail accurate layout designs to enable costing for site works requirements for processors**

   Following on from the previous point, footprint and layout designs were developed for the variations of the scribing concept. This was taken to the next level of detail while outlining what an initial project may look like, and outlining what the scope of supply for the processors may be (primarily the rail works, and any building works required).

4. **Perform detailed cycle time analysis with concept for different cut configurations, including simulations**

   In this project, the concepts were modelled with simulation software to determine accurate cycle times for different cutting configurations at different throughput rates. These simulations also helped drive the design by identifying any reach issues/singularities with the robots and ascertaining where the robots should be located with respect to the carcase stabilisation mechanism. They also allowed the positioning and fields of view for the sensors to be confirmed, together with any potential occlusion issues with the robot.

5. **Investigate Hot vs Cold carcase processing by the system**

   The requirements of the concept were developed for processing hot versus cold carcases.

Intelligent Robotics is working with a number of processors to tailor the concepts for their operations, with the target of progressing them into projects for full production installations.

2.0 Introduction

AMPC's 2020-2025 Strategic Plan identifies both within the Advance Manufacturing (pages 5 & 6) and People and Culture (pages 10 & 11) programs that:

- Removing staff from dangerous operations, via Hands-Off processing (Adv. Mft.),
- Carcase Primal Profitability Optimisation, via acc, and urate processing (Adv. Mft.)
- Digitisation, via acquiring product information and leveraging data insights (Adv. Mft.),
- Attraction, via demonstration and developing a wide range of operations (People & Culture),
- Retention, via improving working conditions and making tasks exciting (People & Culture),
- Development, via developing tasks that require higher skills and intellect – operational & technical (People & Culture),
- Safety and Wellbeing, via reducing the high-risk nature of processing operations (People & Culture),

are all foci of AMPC, and that this one innovation theme will aim to make a significant impact upon all seven.

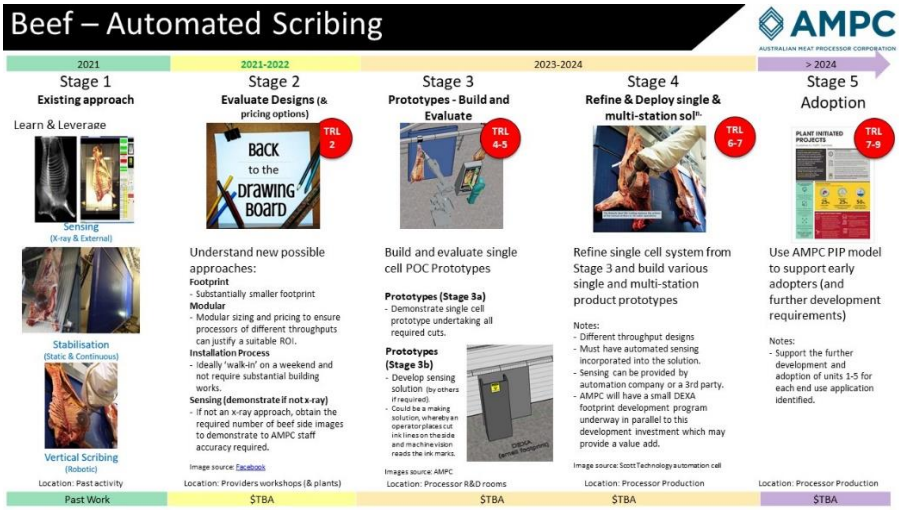
As such although the primary goal for the innovation theme is a successful development(s) to enable operational staff to undertake beef scribing without having to hold onto the beef scribing saw, it is expected that all stages and successful development companies will keep in mind both the primary and secondary goals in the context of the above seven(7) strategic plan touch points.

Innovation Competition

AMPC is anticipating operating an innovation competition with this (and other) innovation themes. Following a widely practiced approach of other innovation investors (such as DARPA), AMPC where possible will support a number of providers with unique approaches during Stage 1 (and 2). As the stages progress the number of providers supported to the subsequent stages will be reduced.

Development Path (and adoption / path to market)

To provide guidance in the AMPC proposed stages of development for this area of innovation, AMPC has drafted the following Theme on a Page. Note: this is a suggestion only, and providers can ignore this approach and or provide an alternative. However, for any provider who proposes a different approach, AMPC will only consider an application if an equivalent development and path to market strategy (similar to the one below) has also been provided.



Additional information can be found at these two links:

- Part 1 - https://www.linkedin.com/pulse/automated-beef-scribing-new-approach-required-modular-sean-starling
- Part 2 - https://www.linkedin.com/pulse/automated-beef-scribing-new-approach-required-modular-sean-starling-1c

Stage 2 – Evaluate new design concepts (with demonstration of vision/sensing approach if applicable)

Stage 2 will enable robotic/machine development companies/integrators/researchers to work with AMPC and Industry to ascertain if the following is achievable as a design for an automated beef scribing solution for the Australian industry that achieves the following aspirations:

1. Modular (applicable to a range of processing plants from an ROI perspective)
2. Smaller footprint (both x-ray and robotic cell components)
3. Ability to 'walk-in' the solution and install on a weekend.

Notes:

- For KPI #2 AMPC also has a current Innovation Challenge pertaining to a Small Footprint DEXA.
- The solution does not need to be x-ray enabled, however, AMPC will need to be convinced during the next stage of investment that the required accuracy can be achieved without the reliance on x-ray sensing, via a sensing demonstration on a processing facility (in Australia or international location).

3.0 Project Objectives

The first iterations of the approach resulted in a semi-automated system being evaluated at NCMC. Information on this development can be located at this link - **Semi-Automated Scribing development**. Although this system did not remain in operation it did demonstrate the benefit of achieving accurate cut lines and removing operational staff from this dangerous task. A semi-automated approach is still an important offering for some processors and as such AMPC has a separate Innovation Challenge under the heading of Gamification to address this market need, see **Remote Operations (Gamification)**.

Machinery Automation and Robotics (MAR) then worked with **JBS** (funded by MAR, JBS, AMPC, MLA & the Australian Federal Government) to evolve this concept into an automated solution. The solution details can be located at this link - **Automated Scribing development** and is still in operation at JBS today.

To this end, AMPC would like to hear from researchers and commercial developers to work with AMPC and the industry to understand if we can improve on the current offering. The objectives of the project are to:

1. Develop an automated scribing concept and assess its alignment with the following aspirations:
    - Modular (applicable to a range of processing plants from an ROI perspective), with scalability assessed for increasing units in series and in parallel in terms of throughput rates and cost
    - Smaller footprint (both x-ray and robotic cell components)
    - Simpler installation.
    - Able to perform a number of cuts
2. Perform design and equipment selection tasks to provide accurate costing for the cell concept in terms of commercial price and cost of further development
3. Detail accurate layout designs to enable costing for site works requirements for processors
4. Perform detailed cycle time analysis with concept for different cut configurations, including simulations
5. Investigate Hot vs Cold carcase processing by the system

The targeted project outputs and deliverables were:

1. Modular (applicable to a range of processing plants from an ROI perspective)
2. Smaller footprint (both x-ray and robotic cell components)
3. Concepts for hot and cold carcase processing
4. Draft high level installation process/plan for consideration by AMPC.
5. Animations/Simulations/Mixed Realty demonstration of the proposed concept(s) along with cycle time analysis
6. Provisions of $RRP (CAPEX – ex-works and installation, & OPEX) and development funding required
7. Designs for the following throughputs 50, 75, 150, 200, 250 head per hour
8. Schedule and timeframe for development activities and first installations

4.0 Methodology

The methodology for conducting the project was as follows:

1. Perform robot selection – engagement with supplier and selection of suitable equipment
2. Draft initial layout
3. Mechanical design for all mechanical components, including quoting
4. Saw tool design and selection for most appropriate cutting tool(s), supplier engagement and selection, and quoting
5. Sensing design for all sensing requirements, supplier engagement and selection, and quoting
6. Electrical design for all controls and electrical equipment required, supplier engagement and selection, and quoting
7. Detailed cycle time analysis and simulations
8. Finalise layout and determine scope required for site works
9. Develop schedule and costings for development, initial systems, and repeat systems, including commercialisation plan

5.0 Project Outcomes

Throughout this project a concept for an Automated Beef Scribing system was developed which was more modular and able to cover a wider range of the Australian red meat industry's needs than current solutions in the market through being able to process a wider range of cuts, ability for difference sensing front-ends (x-ray, AI, or semi-automated user interface), ability to process hot and cold carcases, and the ability to scale the solution effectively based on the cuts desired and the throughput of a given plant. The possibility to drive the system without using x-ray sensing greatly simplifies the installation required. Intelligent Robotics is currently working with processors to progress the concept into commercial installations.

5.1 Smaller Footprint

The concept developed by Intelligent Robotics is scalable depending on the throughput and cut requirements of the individual plant. In its smallest footprint option the cell is approximately 5.1m long and 5.5m deep. This includes infeed and outfeed index stations with the safety mats positioned below them to ensure compliance to the relevant safety standards for the robot and cutting saw. This is in contrast to an existing rib cutting system which requires approximately 12.5m x 7m.

Throughput for the system can then be scaled by putting units in series or in parallel, or by progressing to a continuous based system where a single-robot system is approximately 9.8m long x 4.8m wide.

5.2 Modularity / Scalability

The system itself has been designed to be modular and scalable depending on an individual site's needs regarding cuts to be performed, throughput required, and the space available in the plant.

With the indexing concept, the cells can be added in series or parallel in order to make up the required cycle time.

Similarly for the continuous concept, cutting modules (consisting of a robot, cameras, and carcase stabilisation) can be added to obtain greater throughput.

5.3 Simpler Installation

A key advantage to the current concept is that it can be driven by multiple sensing modalities, including x-ray, AI, or semi-automated operator interface.

In the case of x-ray, the system is much simpler to install due to the design of the Intelligent Robotics Small Footprint DEXA system (refer to AMPC project 2021-1157).

In the case of AI or semi-automated operator scribing, the installation is simpler again as the x-ray component doesn't need to be installed, and becomes a fairly standard robotic cell installation.

5.4 Layout and Indicative Commercial $RRP

Layouts for the different variations of the concept have been developed within the project, and indicative $RRP have been developed.

5.5 Hot vs Cold Processing

The system has been designed to be able to process hot as well as cold carcases. The design for the system was driven by the results obtained in another AMPC project (2021-1200) which examined the stability of hot carcases on while spine cuts were placed. Only the spine cuts were examined (through bone only) as there doesn't appear to be any desire by the industry to place rib cuts on hot carcases due to instability in the side that would cause, as well as hygiene concerns regarding the significant bone dust generation pre-chiller, and potential negative impacts to tenderness due to removing so much rigidity from the carcase pre-rigor. It has also been factored in that the cutting speed when processing hot carcases will be slower than on cold carcases.

6.0 Discussion

6.1 Existing Commercial Systems

The only currently operating commercial beef cutting system requires approximately 7m x 12.5m for X-ray Scanning and one cutting robot as per Figure 1 below (Trieu, Ford, & Shirazi, 2016). Such a solution cannot currently split the x-ray component from the cutting component, so this footprint is required in one contiguous space. It is currently only commercially available for performing 2 rib cuts, from rib 2 to 8. It is capable of operating at line speeds of up to 260 head/hr for performing these two rib cuts on cold carcases only. There are no current commercial installations performing any spine cuts, or any cuts on hot carcases. This system has been used a reference point when assessing footprint.

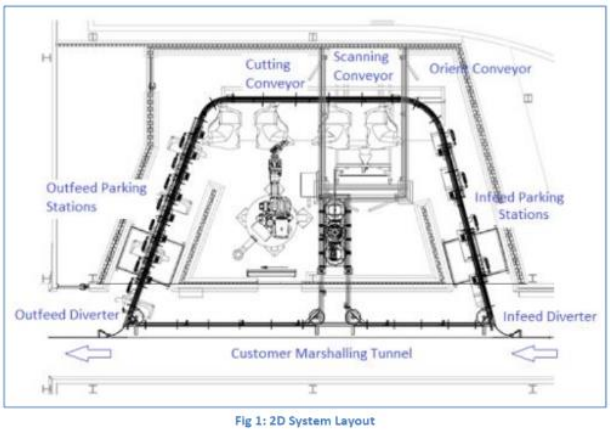


Figure 1 - Existing commercial x-ray cutting system (Trieu, Ford, & Shirazi, 2016)

6.2 Concept Overview

A number of concepts were explored in the initial stages of the project before settling on its final design, taking into account learnings from a number of trials as well as reviewing the risks of each concept.

This final concept possesses a number of key benefits which reduce risk significantly:

1) **Reduced cost due to decreased amount of x-ray hardware and shielding, for a given throughput, if x-ray is used as a sensing front-end.** The final concept is capable of approximately 150hd/hr per x-ray module, depending on the cuts required, if x-ray sensing is desired to drive the automated cutting.
2) **Flexibility in sensing for market coverage.** The new "Automated Beef Scribing" module can be paired with a Small Footprint DEXA for x-ray sensing, or with AI or semi-auto sensing. The sensing front ends will be interchangeable with the system, which will be designed in a highly modularised fashion. This allows the design to cater to a wider market across different budget ranges.
3) **More readily scalable.** For throughputs lower than 150hd/hr, the number of cuts performed can be easily scaled by adding or removing Scribing modules to allow greater flexibility with less cost than the original concept.
4) **Greater footprint flexibility.** There is greater flexibility for customers with how the Scribing modules are positioned with respect to each other, and the sensing front-end (e.g. Small Footprint DEXA).

5) **Indexing or Continuous Operation.** The current concept can either be adapted for indexed operation or continuous operation. Continuous operation can allow for greater maximum throughput in some circumstances, whereas indexing may provide an opportunity for smallest overall footprint.

The updated Scribing concept is novel in its design from anything currently available on the market due to:

- Ability to separate the x-ray scanning and cutting
- Ability to operate with AI or semi-automated user interface as a sensing front-end
- Ability to do the three spine cuts, as well as two rib cuts
- Can be operated as an indexing or continuous system
- Modular design of the Scribing system will enable simple upgradeability and scalability regarding cuts which are performed
- Hydraulic saw is utilised to lower risks relating to saw stalling

6.3 Simulations - Reach Analysis, Robot Selection, Cycle Time

Simulations were created for the concept for both indexing, and continuous operation to confirm the reach and achievable cycle times.

In terms of reach, the robots were able to reach all the desired cut locations without any issue once the robot was optimally placed.

The cycle times were then evaluated, considering both hot cutting and cold cutting. First, the continuous scribing system was evaluated. The throughputs achievable with one robot are significantly higher than an indexing solution, as would be expected.

For an indexing system, additional time is required on top of the cutting to allow for carcase transport and presentation. The throughputs achieved per module were assessed using the simulation to understand what cycle times could be met for various configurations of cuts.

6.4 Electrical Design and Equipment Selection

The electrical design of the system and equipment selection was performed during the project. As part of the Automated Beef Scribing System, there are two main components. The external system, and the Robotic Cutting Cell.

External Control System

PLC and Primary Control System

The external control System of the Automated Beef Scribing System contains the PLC and the control of the carcase transport and stabilisation systems. The chosen controls platform was selected due to its flexibility in controls and the advanced algorithms included within their libraries.

Drives and Motors

The next component to be chosen was the drives and motors, to control the various moving mechanisms. These were matched with the PLC to allows its powerful motion libraries to be fully utilised. Motors capable of withstanding abattoir conditions were chosen.

Robotic System

The second part of the system is the Robotic Cutting Cell. This machine consists of the robot, hydraulic drive, safety PLC and IO.

Robot

The robot selected for this system is a capable of operating within the requirements of the meat industry.

Safety PLC

A safety PLC had to also be chosen to control the robot's safety circuits. Through analysis of a range of different safety control systems, the selected safety PLC was chosen due to the:

1) The ability for decentralised control (each remote IO header is a safety PLC)
2) The scalability of the PLC
3) The ability to use an EFI Bus to talk between all safety nodes, and to use CIP Safety communications protocol to communicate to safety nodes from other providers

IO

The last components to be chosen for the system, is the IO. There are pneumatic cylinders designed into the system to protect the vision cameras, and as a result the primary IO system was selected as a fieldbus-based system capable of natively controlling pneumatic directional control valves.

In addition to this, IOLink was required to allow a large amount of information to be passed to the Robot controller regarding the Hydraulics and the automated washer (pressure and temperature). IOLink is a way to communicate a large amount of sensor information with a low wiring requirement. As a result, an IOLink master was chosen to talk to smart pressure and temperature sensors.

Sensing Components

The concept Automated Beef Scribing modules which have been described have been designed to operate with multiple different front end sensing options:

1) **Small Footprint DEXA** – a DEXA module positioned upstream of the Automated Beef Scribing modules would perform an x-ray scan, and capture colour and 3D images to determine the cut paths for a given carcase (refer to AMPC project 2021-1157).
2) **AI** – sensing positioned upstream of the Automated Beef Scribing modules would determine the ideal cut locations, coupled with advanced machine learning algorithms (refer to AMPC project 2021-1222).
3) **Semi-Auto** – a camera positioned upstream of the Automated Beef Scribing modules would take an image of the beef carcase, which is then presented to an operator who marks key points of interest via a customised web interface. Cut profiles are then generated from these key points coupled with image processing and 3D sensing (refer to AMPC project 2021-1194).

The sensing required for each option was designed and the sensors were specified, including any lighting required by the system.

System Architecture

Based on the system design, the system architecture for the Automated Beef Scribing system was developed. Both the controls topology and the power topology were developed, to confirm the way in which the components interacted and how the safety components worked.

6.5 Mechanical Design and Equipment Selection

The automated scribing design concept needed to take into account various customer requirements and configurations. Some of the variables we needed to account for included: -

- Site layouts (Space)
- Customer throughput requirement
- Carcase mounting technique
- Carcase cut specification
- Hot vs Cold carcase cutting

Due to the wide range of variables to account for, we could not opt for a single design concept which could be replicated on all sites. Instead, we opted to keep some design aspects consistent and customise around these consistent design features to accommodate for any unique or differing site requirements.

In order to determine the design features to be kept consistent, we needed to focus on our project goals and key performance indicators. These included-

- Cut accuracy
- System speed
- Hygiene requirements
- System footprint
- System serviceability

Out of these key customer requirements, we needed to ensure our cut accuracy and system speed would meet customer requirements as a high priority since these factors would weigh heavily in influencing the value-add capacity of our product. If the system was unable to achieve the same, if not, better accuracy as opposed to the existing operating methodology, then customers would find it difficult to see the benefit in such a system. Keeping this in focus, we were able to make a decision on various design options.

System Modularity

In order to implement a high level of system adaptability, one of our goals throughout the design conceptualisation phase was to create a modular system. This is so that we could accommodate a rage of different scribing applications as well as site layout specifications whilst keeping our core design within the scope of each module the same. Another benefit of implementing this modularity in the system is the ease of expansion if the customer requires a throughput increase or a unique cutting application in the future. Our modules would need to adapt to three different scribing applications, these include: -

- X-Ray Scribing
- AI-Automated Scribing
- Semi-Auto Scribing

6.6 System Concepts – Layouts and Indicative $RRP

A range of variants to the concept were developed covering both indexing and continuous operation. The trade-off between these two streams of variants were primarily footprint (smaller for indexing solution) versus throughput (faster throughput for continuous operation). Within these streams additional variants were outlined showing how modules could be added or removed depending on a processor's throughput requirements based on the number of cuts they needed to process.

Each of these concepts was then costed to give an indicative $RRP. Layout drawings were also drafted to show the footprint requirements for each variant.

This information can be used to build an optimal system for a given processor, allowing best coverage across the Australian red meat industry.

6.7 Site Concept (Initial System) – Layout, Site Works Scope, Development

In order to provide a more detailed outline of the system in a commercial setting, one of the concepts was expanded upon to include a carcase turning mechanism (refer to AMPC project 2021-1221 Beef Carcase Orientation Study), the site works required, and the development cost that would be associated with the concept as an initial system.

The full scope of supply was provided together with an indicative list of the customer's scope of supply. The development activities were then outlined and a prospective project scheduled was given.

6.8 Commercialisation Plan

With the system being a new concept, it is expected that the first few installations will require varying levels of development, as has been the norm with introducing cutting systems into the red meat industry in the past. The initial projects will cover the initial development of the system as well as the extended periods of factory testing and commissioning which will come with the early iterations of the new machine. Further optimisations to the design would also be expected in the first few systems, including re-work and re-design.

With the first installations, industry open days could be used (pending customer approval) to grow awareness in the industry of the technology and drive further roll-out. Other marketing mechanisms such as webinars could also be performed, particularly in collaboration with AMPC.

Dialling in the core functionality of achieving the key scribing cuts for cold carcases (and potentially hot carcases) across plants with different throughputs and cattle types would be the core focus for the initial installations. As that core technology matures and the system becomes a commercial offering without any required development, the focus will shift to continuous improvement to ensure the technology continues to deliver value to the industry and remains a market leader.

The scribing concept has been presented to a number of processors to date. Initially, these were presented as x-ray sensing variants (both indexing and continuous). While the footprint was smaller and more flexible than existing systems, most sites still had an issue with fitting the system onto their plant effectively. The higher cost was also a concern. An AI-driven alternative was presented after the results from AMPC project 2021-1222 indicated that good accuracy was achievable without the x-ray sensing. This concept was better aligned with their commercial targets, with concept development and sales work progressing with some processors for scribing systems.

7.0 Conclusions / Recommendations

An automated scribing concept has been successfully developed consisting of a suite of variations to be able target as wide a customer-base as possible across the Australian beef industry. When reviewing the objectives of the project:

1) **Develop an automated scribing concept and assess its alignment with the following aspirations:**
   modular (applicable to a range of processing plants from an ROI perspective), with scalability assessed for increasing units in series and in parallel in terms of throughput rates and cost;
   smaller footprint;
   simpler installation;
   able to perform a number of cuts

   Regarding *modularity*, the concept developed consisted of a number of variations (indexing vs continuous, x-ray vs AI vs Semi-Auto sensing) which could be 'stacked' together to meet the throughput requirements of any given plants for the cuts they wished to perform. The programming as well as the electrical and mechanical design of the system will facilitate this modular approach such that minimal customisation is required to perform this scale up or scale down for different customers, and to allow an element of expandability into the future.

   With respect to *smaller footprint*, the indexing variation of the concept with one robot is the smallest footprint that was achievable (approximately 5.1 x 5.5m), significantly smaller than the existing beef rib cutting solution within industry, but also lacking x-ray sensing. Once x-ray sensing is added, both the indexing and continuous variations are still of a smaller footprint to existing solutions, while also being able to perform more cuts and with added flexibility for the footprint.

   The aspiration of a *simpler installation* was the most challenging due to the large nature of beef carcase sides (up to 1.5m in width and hanging off a 4m+ overhead rail). While not able to be strictly described as a 'walk-in' solution, the concepts have been simplified as much as possible in terms of installation scope, and could conceivably be installed over a weekend given unencumbered access over the full weekend once the system has matured as a commercial repeat system and installation procedures have been optimised. One of the key aspects of the installation – interfacing with the customer chain for feeding and removing carcase sides – would vary for each individual customer depending on their current layout and process flow.

   The system has been specifically designed with the goal of performing a greater *number of cuts* than has been achieved previously in the beef industry. Namely, the ability to perform at least three spine cuts (the chuck/cube roll separation scribe, the quartering scribe, and the lumbosacral junction scribe) as well as two rib cutting scribes.

2) **Perform design and equipment selection tasks to provide accurate costing for the cell concept in terms of commercial price and cost of further development**

The design of the concept was developed to a detailed enough level to enable accurate costings to be developed. The design for the different concepts were outlined in detailed, as well as the expected commercial $RRP for each concept, and a detailed outline of what the initial projects may look like in terms of costing and structure, factoring in broader site integration aspects such as automated carcase turning.

3) **Detail accurate layout designs to enable costing for site works requirements for processors**

Following on from the previous point, footprint and layout designs were developed for the variations of the scribing concept, as outlined in this report. This was taken to the next level of detail in this report while outlining what an initial project may look like, and outlining what the scope of supply for the processors may be (primarily the rail works, and any building works required).

4) **Perform detailed cycle time analysis with concept for different cut configurations, including simulations**

In this project, the concepts were modelled with simulation software to determine accurate cycle times for different cutting configurations at different throughput rates. These simulations also helped drive the design by identifying any reach issues/singularities with the robots and ascertaining where the robots should be located with respect to the carcase. They also allowed the positioning and fields of view for the sensors to be confirmed, together with any potential occlusion issues with the robot.

5) **Investigate Hot vs Cold carcase processing by the system**

The requirements of the concept were developed for processing hot versus cold carcases. The design was driven by the results obtained in another AMPC project (2021-1200) which examined the stability of hot carcases while spine cuts were placed. Only the spine cuts were examined (through bone only) as there doesn't appear to be any desire by the industry to place rib cuts on hot carcases due to instability in the side that would cause, as well as hygiene concerns regarding the significant bone dust generation pre-chiller, and potential negative impacts to tenderness due to removing so much rigidity from the carcase pre-rigor.

A number of processors have expressed interest in the beef scribing concept and Intelligent Robotics is working with them to tailor the concepts for their operations, with the target of progressing them into projects for full production installations.

8.0 Bibliography

Trieu, W., Ford, M., & Shirazi, M. (2016). *P.PIP.0288 JBS Dinmore Beef Rib Cutting MLA Public Report.* MLA.