final report

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Semi automated beef scribing

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Abstract

Scribing of sides of Beef is a task that is currently performed manually by operators utilising a hand held circular saw. This task is arduous and due to the accuracy required to maximise yield cannot be performed by and unskilled person.
Automating this task has the potential to benefit a processor in terms of labour reduction, suppression of OH&S claims related with the task, operational improvements, boning room efficiencies and Yield gains achievable.
This project utilises a vision system and a robot to semi automatically scribe beef sides and prove that with more development work use of an automated beef scribing system in a production environment is a reality.

Executive Summary

Scribing of sides of Beef is a task that is currently performed manually by operators utilising a hand held circular saw. This task is arduous and due to the accuracy required to maximise yield cannot be performed by and unskilled person.

Automating this task has the potential to benefit a processor in terms of labour reduction, suppression of OH&S claims related with the task, operational improvements, boning room efficiencies and Yield gains achievable.

This project set out to utilise a vision system and a robot to implement a semi-automated scribe point location system. That is to have a camera take an image of a side and have an operator, seated at a computer terminal, identify the scribe point locations on the carcase using the PC terminal mouse to click on the start and end points for each scribe cut.

Following development of the vision system at Machinery Automation and Robotics (MAR), the intention was to install the Robotic scribing system in a purpose built room at Northern Cooperative Meat Company (NCMC) at Casino NSW. Due to construction issues on site at NCMC it was not possible to construct the room in the desired location and the system was setup in one of the chillers. This created a number of issues which altered the way in which the system was laid out and the development and design of the systems components. The main issues are centred around the height of the room and the transport rail system making it difficult to process larger animals and restricting the speed with which the carcases can be transported into and out of the system.

Despite this the system has been successfully commissioned in the chiller and is capable of processing approximately 340 carcases a day.

This rate is obviously not acceptable for high volume production and further development is required in the following areas:

- Room layout and increased rail height
- Backing board design (possible moving backing board)
- Further refinement of the vision process and possible use of a 3D camera system
- Development of automatic scribe mark placement
- Carcase rotator
- Sterilisation system

Contents

1 Background

When this project commenced in 2005, automated robotic scribing was being used in Pork processing overseas, MLA was sponsoring similar automation projects for other sheep processes and preliminary work had been carried out by Food Science Australia on the scribing of beef sides. The task of scribing the side of beef is performed manually by operators and is the first point at which yield can be lost in the boning room. Once these initial cuts have been made there is nothing that a boning room operator can do to alter the cut paths to reclaim valuable meat which may have been left on the lower price side of the cut line, hence this task cannot be performed by an unskilled person due to the accuracy required to maximise yield.

Scribing is an arduous task involving many associated OH&S risks. These include repetitive strain injury, potential for back and shoulder injuries and amputation risks due to the cutting saw.

Hence there is a desire in the industry to automate this task to increase yield and eliminate the OH&S issues

2 Project Objectives

The objective of the project is to develop, trial and demonstrate a semi automated beef scribing process. This is to be achieved by designing, and testing the process at MAR's workshops before installation of a system at Northern Cooperative Meat Company (NCMC) in Casino NSW where the system will be commissioned and used in production.

3 Approach and Methodology

The descriptions in this section detail the initial planned approach, scope and supply for the project. As will be seen in Section 4 various circumstances led to significant modifications to this design, scope of work and operation of the system.

3.1 System Principles and Design

System is to identify the scribe points on a side of beef, then automatically perform the scribing operations & sterilise the saw blade to the current AQIS standards.

- The robot system is expected to scribe the following;
    - 180-220 bodies per hour, 360-440 sides per hour, dependant on size of the body and number of cuts required, the final throughput will be determined after stage 1. Expected cycle time is as follows,

Rail Transportation time	4 seconds
Stabilisation time	3 seconds
Vision and processing	1 second
Cutting, dependant on quantity and location of cuts	7-13 seconds
Existing pork system completes 4 scribes in 6 seconds	
Sterilisation	1 second/side (2sec total)

Total 16 seconds per side = ~220 sides per hour x 2 scribe boards = 440 sides / hr
Total 21 seconds per side = ~170 sides per hour x 2 scribe boards = 340 sides / hr
    - Sides weighing from 30 to 250 kilograms
    - Up to 7 cut lines for each carcase, determined through the database & PC Terminal

- The carcase will be presented;
    - Hung from the hind leg in a consistent orientation
- The system is to operate in the following environments
    - Operate in a Chilled environment, typically +5 degrees Celsius or greater
    - Be able to withstand normal wash down cleaning procedures

- Sterilisation procedure
    - The scribing system is to be sterilised upon completing each body, ie after the two sides have been scribed.
    - Sterilisation is to include all carcase contact points and met the AQIS sterilisation specifications.

- System Footprint
    - The scribing system is to service a pair of opposing rails, within an area of 4000mm by 5000mm.
    - Allow personnel access past the line when not in operation
    - Allow personnel to manually perform the scribing operation at the station during installation and commissioning phase of the project.

3.2 System Integration Principles

3.2.1 Robot System

MAR Pty Ltd are to supply the Kuka “Shelf Mounted” robot system comprising the manipulator, controller, software and control pendant.
MAR Pty Ltd;

- is a Systems Partner of Kuka Robotics, receiving their knowledge and experience gained in the development of the Robotic Pork Scribing Systems now in production in Europe.
- fully support both our own robot installations & other installations throughout Australia,
- Provide workshop and on site Kuka Robot system training by our Factory trained engineers

3.2.2 Carcase Stabilisation System

MAR Pty Ltd plan to work with Banss to develop the carcase stabilisation system.
Banss a German based company have already successfully implemented a Robotic Pork Scribing System which uses a carcase stabilisation device.
MAR recognise that the range in beef carcase weights varies significantly compared to those in the Pork industry, and MAR’s wide experience in general automation will be required to complete this important component of the system.

3.2.3 Scribe Location Identification System

This system will incorporate a pair of cameras viewing each side (a total of 4 cameras for the dual chains). An image will be taken of a side, then an operator, seated at a computer terminal, will identify the scribe point locations on the carcase using the PC terminal mouse to click on the start and end points for each scribe cut.
While the robot is scribing one side of the line, the next side is indexed & stabilised. The robot system automatically adjusts the angle of the scribe based on the cut specification for the carcase. The depth of the cut will automatically be determined based upon a high speed solid state contact sensor and the operator selected depth of the cut required.

3.2.4 PLC and Control Equipment

MAR Pty Ltd is a Rockwell (Allen Bradley) Systems Integrator and the equipment to be used will include the following

- PLC – Rockwell (Allen Bradley)
- PanelView – Rockwell
- Control Equipment – Rockwell
- Cabinets – Rittal / special purpose wash down
- Fitting, Cabling and terminations – MAR Pty Ltd
- PLC programming – MAR Pty Ltd

3.2.5 Safety PLC and Equipment

MAR Pty Ltd is a Pilz Systems Integrator and the safety equipment to be used will include the following

- Safety Light Curtains – Pilz, Omron or Sick
- Access Guard Switches – Guardmaster
- System cabling and terminations – MAR Pty Ltd

3.2.6 Robot Elevated frame

- Frame Design – MAR Pty Ltd
- Frame fabrication –External Fabricators

3.2.7 Factory Acceptance Test

FAT at MAR Pty Ltd’s Silverwater facilities.

3.2.8 System Installation through to commissioning

System Installation through to Commissioning by MAR Pty Ltd’s Australian based technicians and engineers, with assistance from Banss, E+V and EFA.

3.2.9 System Training

System Training by MAR Pty Ltd’s engineers.

3.2.10 System Support

System Support by MAR Pty Ltd's technicians, guaranteed 24 hours, 7 days.

3.3 Proposed System Operation

3.3.1 System Start Up

- The operator prepares / checks the saw blade & other components of the system and exits the cell, resetting the Safety System.
- At the HMI panel, the operator starts the robot beef scribing system.
- Servo power is applied to the robot system.
- The first operation for the robot is a sterilisation procedure to clean the blade.
- The beef side is transferred into the cell.
- The beef side is positioned before the stabilisation backing board, which is brought under the beef side to cradle the carcase.
- An image scan is taken by the cameras.
- The System processes the Image and the operator marks the position on the PC screen for the start and end points of each of the scribing cuts . The operator may also identify the type of cut for the scribe points to automatically set the optimum angle for the robot to scribe the carcase.
- The robot system starts the scribing operation for the set scribe points.
- Feedback from the high speed solid state contact sensor during the scribing operation dictates the depth that the saw blade needs to cut.
- The carcase is released, with the opposing line presented to the system for scribing.
- Upon completion of the two sides of the carcase, the system performs a sterilisation procedure on the saw blade.

3.3.2 Completion of Operation

- Once the run of carcases is completed the operator stops the system operation through the HMI screen.
- The robot manipulator moves to a high position above the robot platform with servo power lost from the system once the Safety System is interrupted or an Emergency Stop button is pressed, ensuring safe access through the cell.
- This would also be the location of the robot manipulator if the scribe cuts are performed manually.
- The robot stand is at a height where an operator can pass under.

3.3.3 Cleaning Operation

- To facilitate ease of maintenance of the saw blade and cleaning of the robot system, the operator can select different positions for the robot manipulator to move to. This is completed through the HMI touch screen.
- To minimise the risk of the saw blade becoming a risk to personnel within the cell during the cleaning operation, the robot manipulator could be programmed to automatically insert the saw blade into a fixed protective shroud located on the robot platform.

3.4 Human Control Interface

The Main Operator interface to control the Robotic Beef Scribing System and all peripheral equipment will be the Vision System PC in the operator cubical

3.5 Scope of Work

The Core components of the proposed system are detailed in the sections below:

3.5.1 Robot

One German manufactured Kuka KR60-3 , six axes Shelf Mounted Robot System designed for mounting on an elevated platform.

3.5.2 Robot Base Frame

One Robot Base Frame to support the robot manipulator

3.5.3 Transport Rails

Two 4000mm carcase transport rails

3.5.4 Robotic Saw System

One EFA Robotic Saw System, designed specifically for robotic scribing applications

3.5.5 Saw blade sterilisation system

The saw blade sterilisation system cleans the saw blade and any other contact surface every second side (every body).

3.5.6 Control System

PLC Control Panel for the system control, HMI Operator Interface, cabinet, wiring, installation, control programming and commissioning.

3.5.7 Camera System and PC terminal

- Two Cognex cameras positioned to view each carcase (one pair of cameras per line), housed wash down proof stainless steel.

- The terminal consisting of the PC, screen, keyboard and mouse interfaced with the PLC control system.

3.5.8 Safety Guarding and Emergency Stop

- The robot system will be guarded by an area scanner, positioned in the robotic work zone.

- Emergency Stop switches will be located at 2 positions , at the cell access points.

3.5.9 Carcase Stabilisation Systems

Two Carcase Stabilisation Systems, designed specifically for robotic beef scribing applications

3.5.10 Programming and Commissioning

Programming of the robot systems to complete the robotic scribing of the beef sides.

3.5.11 System Safety Audit

A Safety Audit and Risk Assessment for the system will be provided for discussion and action

3.5.12 Factory Acceptance Test

Pre delivery, the system is setup and programmed at our Silverwater workshops to practically test the key components of the robot system.

3.5.13 Installation of the System

System delivery to your facility and installation during normal business hours

3.5.14 Site Acceptance Testing

At the completion of commissioning, the Site Acceptance Testing of the system will be performed to ensure that the system meets all of the specifications listed in this proposal

3.5.15 Training

- To familiarise the operators in the program structure and robot control, one 3 day training session will be held at Machinery Automation & Robotics' facility.
- To ensure that the operators fully understand the operations of the robot system, 4 additional on site training sessions of 4 hours duration is included to train the operators in the operation of the robot system.
- To ensure that the maintenance personnel fully understand the maintenance requirements of the system, one 4 hour training session on the maintenance requirements is performed on site.

3.5.16 Documentation and Operation Manuals

Two sets of documentation and operation manuals will be provided upon commissioning for the robot systems

4 Results and Discussion

MAR have worked in partnership with Northern Cooperative Meat Company (NCMC) over the past 5 years to develop the Robotic Scribing System that we have today. The system is currently being used in production scribing at a rate of approximately 50 sides an hour.

The project has faced a number of challenges over the past five years that caused the plan described above in Section 3 to be varied. These challenges along with the projects achievements are detailed in the sections below.

As described above in Section 3 the initial intention was to setup a room that would enable carcases to be brought in on two parallel rails with a robot mounted on a platform between the two rails, as shown below in Figure 1.

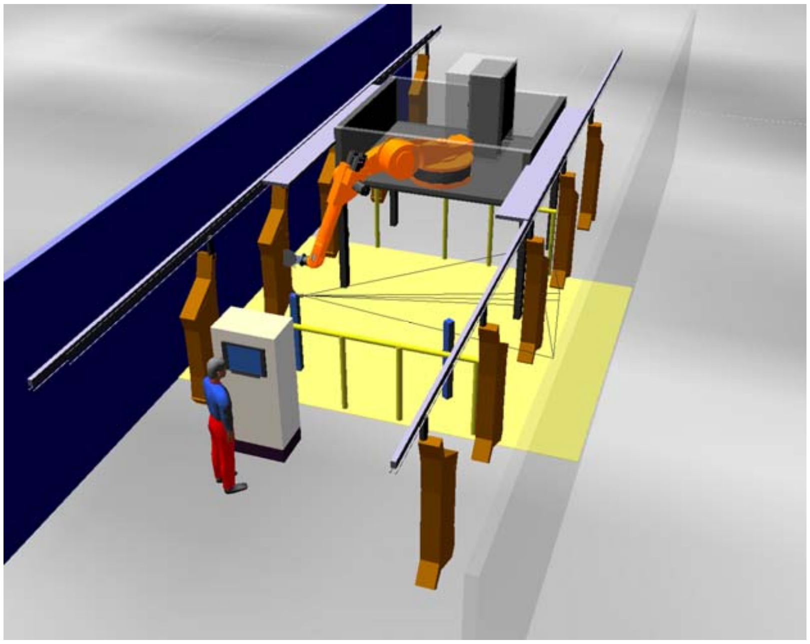


Figure 1

Due to construction issues on site at NCMC it was not possible to construct the room in the desired location. This changed the possible layout of the system as it became evident that it would have to be set up in one of the chillers at NCMC.

The initial backing board and vision trials were conducted in this chiller and as the project progressed the following were added by NCMC/MAR to suit the room:

- Stabilisation System/ Backing Boards
- Vision system
- Robot and Robot base
- Carcase Transport Rails
- Carcase Rotator
- Guide Rails
- Rub bars
- Guarding
- Steriliser
- Emergency Stop System
- Air Conditioned operator room.

The layout of the system as it currently exists is shown in Figure 2 on the following page.

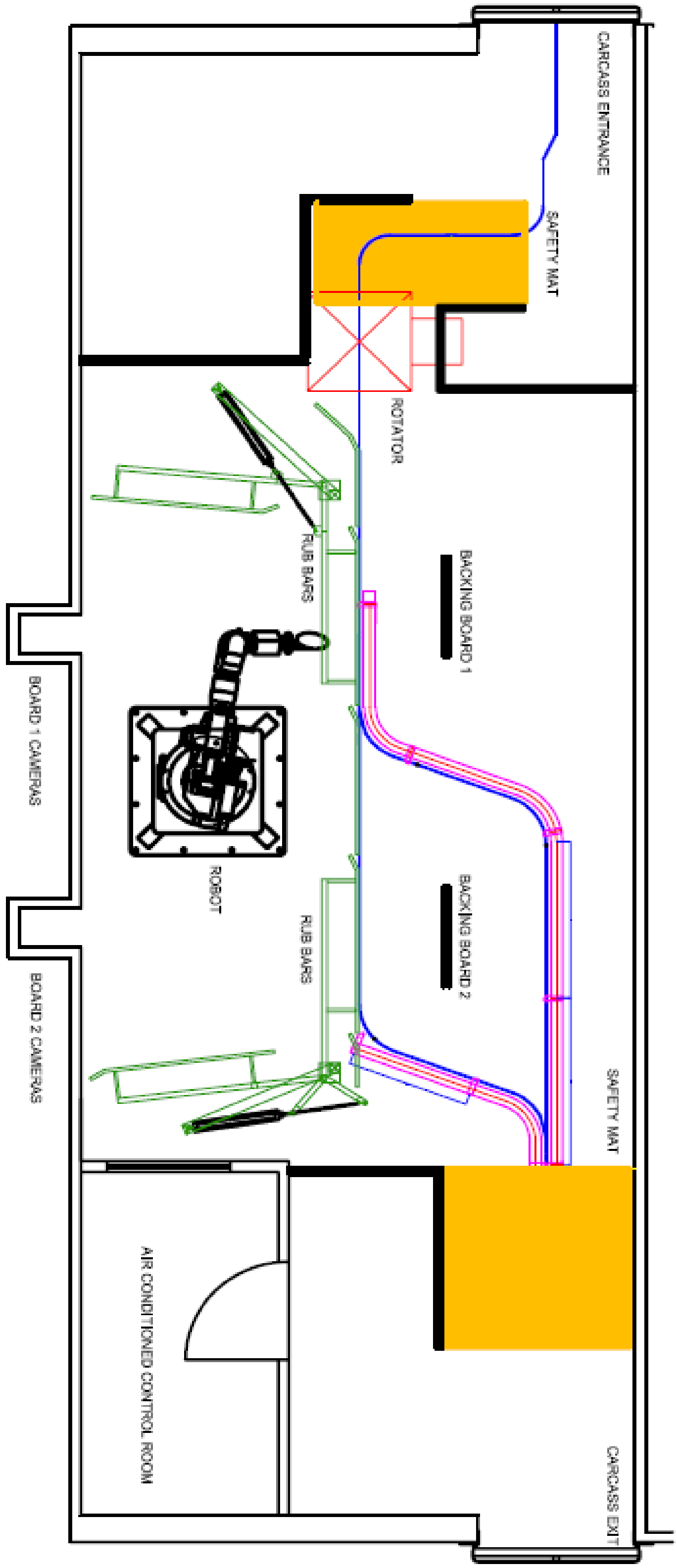

CARCASS ENTRANCE
SAFETY MAT
ROTATOR
BACKING BOARD 1
RUB BARS
ROBOT
BOARD 1 CAMERAS
BACKING BOARD 2
RUB BARS
BOARD 2 CAMERAS
SAFETY MAT
AIR CONDITIONED CONTROL ROOM
CARCASS EXIT

Figure 2

With this set up issues arose due to the location of the chiller with respect to the chillers that stored the carcases. Presentation and removal of the carcases to and from the Scribing chiller involves moving a small number of carcases at a time making it a labour intensive task and inhibiting the speed at which the carcases can be brought into and removed from the room.
The low height of the Chiller ceiling also causes issues by restricting the height of the transport rails causing the larger carcases to catch on various components in the system including the rotator.

The following table details the changes from plan that occurred throughout project:

	Planned	**Actual**
1	A dedicated room to allow parallel transport rails to be constructed and allow easy entry and exit of carcases from the room.	A converted chiller with a low ceiling that inhibits free movement of carcases into and out of the room and restricts the ability to process larger carcases and to meet the proposed carcase throughput.
2	Kuka KR-60 shelf mounted robot	Kuka KR-125/3 robot mounted on a robot base.
3	Two Cognex Vision Cameras per backing board	One Cognex camera a Sick laser scanner per backing board
4	Safety Area scanner for detecting call safety breach.	A combination of guarding, safety mats, Emergency Stop Push buttons, safety start up sequence and start up siren.
5	A Steriliser system that washed the saw blade after every body.	A steriliser system that operates only when commanded by the operator.
6	An EFA Robotic Saw System	A Freund Robotic Saw
7	A plastic backing board based on that used in the pork industry	Corrugated stainless steel backing board.
8		Inclusion of guide rails, rub bars and carcase rotator to ensure correct orientation of the side.
9		Air conditioned operator room
10		Additional lighting to allow production of a silhouette to determine location of clamps.
11	HMI Panel	High definition LCD screen to enable accurate mark up of the scribe marks

4.1 Stabilisation System

The description above, in Section 3, details that MAR were to work with Banss a manufacturer of Pork Processing equipment in Europe to develop the Carcase Stabilisation System, or backing board as it has become known. While the principles of what has been developed by Banss was used as reference, the major development occurred due to the partnership between MAR and Northern Cooperative Meat Company (NCMC) using a prototype backing board that had been developed by Food Science Australia. (The report from FSA with regard to their backing board development which was part of MLA PRTEC.019, is attached as an appendix to this report).

4.1.1 Backing Board Initial trials

The prototype backing board developed by FSA is shown in Figures. 3, 4 and 5 below,

Figure 3

Figure 4

Figure 5

It can be seen from these images that the board is fully manual with struts that can be extended to support the carcase as it hangs from the rail above. The flaps (total of 4) can be manually manipulated and secured in position to support the carcase during the cutting process.
This board was modified at NCMC to incorporate pneumatics to enable the board and flaps to be tilted/adjusted more easily and trials using a manual scribing saw were conducted. The results of these trials showed that the board was inadequate allowing the carcase to roll and slide as the cuts were made. The board was also too small and unable to correctly support the larger carcases.
Figure. 6 below shows the pneumatic modifications made to the FSA board along with the fact that the board is inadequate for the larger carcases.

Figure 6
Figure. 6 above shows the pneumatic modifications made to the FSA board along with the fact that the board is inadequate for the larger carcases.

4.1.2 Linear Rail and Bottom Clamping Backing Board Design

As a result of the initial trials, the decision was made that a new, larger backing board with more flexibility needed to be designed. The out come was a board manufactured mainly from stainless steel chequer plate with the following features:

- the board was mounted at a fixed angle on linear rails and was positioned using a servo drive.
- a greater number (12) of smaller sized pneumatically positioned flaps.
- A clamp was incorporated into the bottom of the board and was pneumatically positioned to clamp the neck

The aim was to provide a board that was able to cradle the carcase better as well as provide a surface on which the carcase was less likely to slide. Stainless was also seen as beneficial during wash down. The carcases would move to position in front of the board and the board would move forward to cradle the carcase. The flaps would be pneumatically positioned according to the weight of the carcase, which had been scanned in prior to the carcase entering the room. As the board moved forward a sensor would pick up the surface of the spine and stop in different positions, depending on the carcase thickness, so as to place the spine surface into a calibration plain for the vision system. The clamp would move up from the bottom of the board and clamp the neck once the carcase was sensed. Figures 7 and 8 below show this setup.

Figure 7

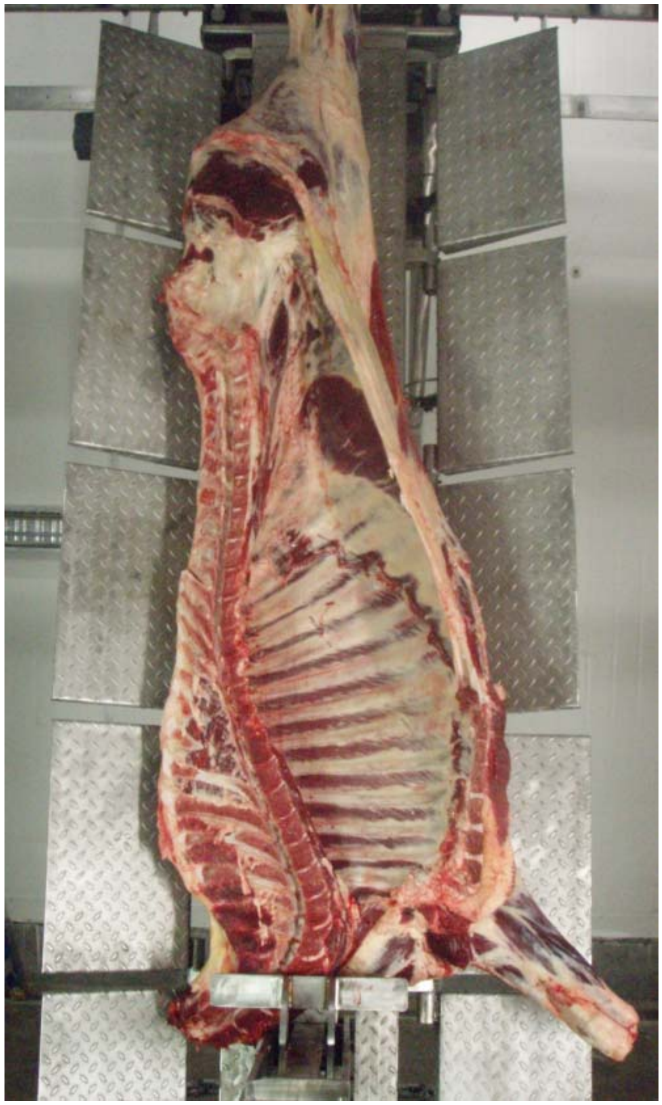


Figure 8

Although this design was an improvement on the FSA version there were still issues with the carcase rolling as the scribing cuts were made. This was mainly due to the inability of the clamp system to adequately hold the carcase. In certain situations the clamp also inhibited the scribing cuts from being made as it clamped too high up on the carcase and interfered with the saw. The clamp was also an issue during board movement, as can be seen in Figure 9 below, interfering with the larger carcases as the board moved in and out.

The multiple flaps on the board also became an issue when cleaning the system with many catch points making cleaning difficult. In addition the linear rail system occupied a lot of real estate, which was now becoming an issue due to the location of the system as discussed in the previous section, and on occasions did not have the length of travel required to correctly cradle the carcase.

Figure 9

4.1.3 Tilting and side Clamping Backing Board Design

Due to the continued rolling of the carcase during the scribing process it was realised that the front leg as well as the neck needed to be clamped and the idea of clamping the carcase from the side was designed into a new board. The clamps were positioned by taking an image of the carcase using the vision system and using servo motors to linearly position the clamps. Once in position the rotary actuators rotated the clamps across the carcase. It was also realised that if the clamps from the side were strong enough they would flatten the carcase enough such that cradling of the carcase by the backing board was no longer necessary. Hence the new design removed the pneumatically controlled flaps from the side of the board and replaced the chequer plate with a corrugated stainless steel sheet. The corrugations assisted in preventing sliding of the carcase as the cuts were made and alleviated any cleaning issues.

The linear rail system was also replaced with a pneumatically controlled board tilting system which used less space and resulted in improved support of the carcases.
The final modifications to the backing board system were made during the Finalise pre production Prototype project P.PSH.0508, where greater accuracy in placement of the clamps was achieved by adding spot lights in front of the board and painting part of the floor and the rear wall a light colour so as to create a silhouette of the carcase which the vision system could use to locate the neck and leg positions.
It is felt that the location of the lighting and taking of the image at this point is not the most appropriate mainly due to the location of the lights and their interference with passing carcases. Further development in a future project, if tilting backing boards and clamping are to be used, would be that this image would be taken at a station prior to the backing board where the lights could be positioned more easily and avoid interference with carcases. The images in Figures 10 and 11 below shown the clamps clamping the neck and leg and a rear view with the boards in the retracted position.

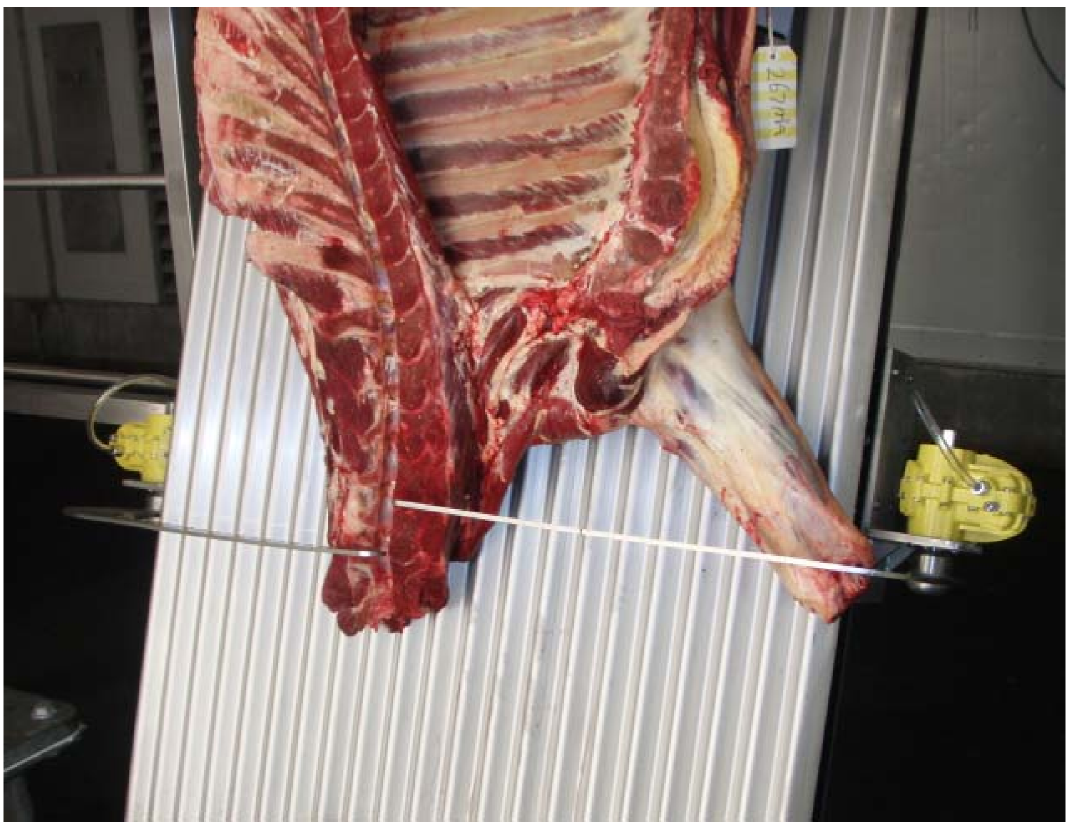


Figure 10

Figure 11

4.2 Vision and Sensing System

4.2.1 Initial vision trials and FAT at MAR

Initial trials of the vision system were conducted onsite at NCMC to ensure the Cognex Oscar camera was suitable for obtaining images of the carcases. During this process it was realised that the required results could be achieved using one high resolution Cognex camera rather than the two initially proposed.
Although it was initially proposed that the system be setup as a semi automated scribing system, MAR did conduct trials to see whether it was feasible to fully automate the scribing process, that is where

- the carcases would come to position and be supported by the backing board
- an image would be taken of the carcase and scribing marks automatically placed on the image provided on the screen to the operator
- the operator would view the marks, make slight adjustments if required and then press accept at which point the robot would make the required cuts.

Trials were conducted to determine whether the images generated from the camera were able to be used by the Vision Pro and Visual Studio .Net software to successfully identify features on the carcases and allow pattern matching to occur. A library of images of carcases was built up to allow animals of different breads and sizes to be identified and once identified have the scribe marks automatically placed on the image provided to the operator.
Further trials were conducted at MAR's workshop using a life size photo of a side shown below in Figure 12

Figure 12

These trials showed that the system was able to correctly identify carcase features, place the scribe marks with reasonable accuracy according to breed and size and send the robot to the correct location on the image to make the scribe marks. The system was successfully FAT'ed at MAR at this point.

4.2.2 Vision Development onsite at NCMC

Once the robot and vision system was installed on site and after trials at NCMC a number of issues came to light:

1) The Cognex camera is a 2D camera and hence unable to give any information in the Z dimension. This proved to be a problem due to the curvature of the spine and the varying thickness of the carcase sides. For each side the surface of the spine ended up in different location or distance from the camera making it impossible to place the scribe marks accurately based on the vision calibration plane that had been set up.
   These issues were overcome with the installation of a 3D laser scanner which was able to supply Z coordinate data (distance of the carcase side from the cameras). There was an initial issue with this as a pneumatic rotary actuator was used to rotate laser across the side. This proved to be jerky in rotation and was replaced by a DC drive and gearbox which enabled smooth rotation of the scanner. Using the Z data and the XY data supplied by the Cognex camera, calculation of corrected XYZ coordinates of the carcase side was possible. With these corrected calculations accurate cutting locations to +- 2mm, were able to be achieved.

2) With the robot accurately cutting with respect to where the scribe marks were placed on the screen a problem was encounter with the automatic placement of the cut marks. Although hundreds of images had been scanned into the system and the cut specifications defined, it was found that the automatic placement of the cut marks was only accurate to approximately +/- 25mm. For the robot to scribe in the correct location the operator was constantly required to adjust the location of the cuts. A change in process was made where by the operator manually placed the scribe marks using the touch screen and touch screen pen in the operator cubicle. This proved to take less time than adjusting the automatically place marks and was adopted as the preferred method.

3) The initial system had the scribing cuts setup up so that they were perpendicular to the backing board with the ability for the operator to manually adjust the angle of the cut. It was difficult however, using only a 2D image on the operator screen, for the operator to judge the angle of the spine. It was deemed necessary, by QA, that to improve yield that automatic angle adjustment of the cuts needed to be incorporated into the system. This was achieved in the Finalise Pre Production Prototype Project P.PSH.0508 by utilising the data generated by the laser scanner, this enabled the angle to the spine to be determined and the required angle of cut to be determined.

4.3 Control System Components

The control system for the Scribing cell is made up of the following main components:

- Kuka KR125-3 Robot
- Kuka KRC robot controller

- Allen Bradley Compact logic PLC
- Pilz Multi Safety Controller
- Vision PC
- Operator Touch Screen
- 2 off Cognex Oscar cameras for 2D image data collection
- 2 off Sick LMS400 Laser Scanners for collection of 3rd dimension data
- 4 off SEW servo motor for carcase clamp positioning
- 1 off Allen Bradley Powerflex 40 VSD for control of the cutting saw
- 1 off Allen Bradley Powerflex 70 VSD for control of the carcase rotator
- 1 off 1.75kw Freund cutting saw motor

The PLC, safety controller, servo controllers and VSD's are all located inside the MCC. This along with the Robot controller and Vision PC and screen are located inside the Air Conditioned Control Room. The robot and the saw motor are enclosed in a 'robot bag' to protect then from water ingress during wash down, this is shown in Figure 13 below.

Figure 13

4.4 Cutting Saw

The project began using a 1kW EFA saw previously used in the scribing of pigs. It was found that due to the increased density and hardness of the beef bones this saw was unable to successfully make the required scribing cuts without stalling. This saw was replaced with a Freund 1.75kw saw. Due to the extra motor power and increased gearbox size and ratio the result using the Freund saw have been much better.

4.5 Rotator

A carcase rotator and guide/rub bars were built by NCMC to ensure the carcase is correctly orientated prior to the carcase arriving at the backing boards. As the carcases enter the rotator they are scanned by a laser scanner which determines whether it has the convex or concave side of the side of beef facing it. If this sensor detects convex then the side is rotated, if it detects concave the side passes straight through the rotator.

Issues have been experienced with the rotator especially with regard to larger carcases. These carcases catch on the rotator and do not rotate correctly. The problem here is the height of the room that restricts the height of the transport rails. In the current location there is no ability to modify the Rotator to overcome these issues and further work will be required in a subsequent project to obtain consistent carcase rotation.

Figure 14 below shows the rotator and rub bars from inside the cell.

Figure 14

4.6 Saw Blade

A number of different Saw blades have been trialled throughout the course of the project. Saws supplied by both EFA and Freund have included non tipped, toothed, and knife edge blades. The knife edge blades have produced the best cutting results however these went blunt after only processing about 50 carcases. The blade currently being used is an EFA tungdten tipped saw blade which is providing very good cut quality and is able to cut in excess of 1000 carcases before requiring resharpening. Continued use in production is required to determine the ultimate life of this blade.

4.7 Emergency Stop/Safety System

As part of the Finalise Pre Production Prototype project P.PSH0508 a Risk assessment was conducted by MAR, reviewed by NCMC and verified by a third party. As a result of this modifications were made to the system that had been installed to make it more 'user friendly' while maintaining the Category 3 safety rating. The main components of the system are:

- Safety pressure mats at both entrances to the robot cell as seen below in Figure 15

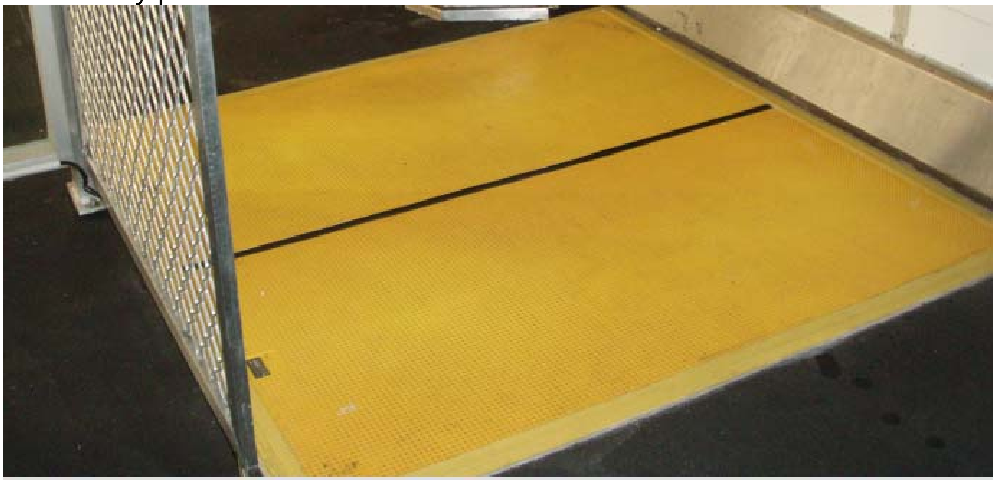


Figure 15

- A combination safety reset procedure that involves pressing a reset button inside the cell, where all of the cell is visible, exiting the cell and therefore activating the safety mat, then pressing a reset button at the entrance to the operator enclosure.

- A reset siren sounds from the moment the button is pressed inside the cell, warning everyone that the safety system is about to be reset. The siren stops once the cell safety is reset with the button on the outside of the cell.

- The Conveying system will commence to operate after the safety system is reset but the Robot will not commence operation until the operator resets the robot on the HMI screen and sends the robot cutting coordinates.

- 3 emergency stop push buttons have been installed inside the cell to enable anyone in the cell to stop the system and prevent it from being reset while they are in the cell.

Floor scanners, shown below in Figure 16 that were originally used in the cell have been removed due to false tripping caused by water droplets and interference from the backing boards.

Figure 16

4.8 Air Conditioned Control Room

An air-conditioned control room was built to house the electrical control panel, operator screen and vision PC. This room allows the operator to work in a quiet, temperature controlled location and also protects the equipment during wash down. The room and its location in relation to the robot and backing boards is shown in Figure 17 below.

Figure 17

4.9 Steriliser

Due to the limited space it is difficult to locate a steriliser that can be used without interrupting the system cycle. During the initial phase of system setup a steriliser was placed behind the robot and the operator controlled when the robot went to the sterilising position. As the project continued however, it was found that some of the cuts made on Board 1 interfered with the sterilisation tank in this position. The tank was moved and is now located underneath the robot and again movement of the saw to this position is initiated by the operator really just as a means of cleaning the saw of bone dust build up. For this to occur there needs to be no carcase in front of Board 1 and Board 1 needs to be fully retracted, other wise collision with the robot/saw will occur. This is obviously not an acceptable situation for a full production environment and re design of steriliser location will need to occur in future projects.

4.10 Guarding

A combination of Safety Glass and mesh guarding has been used in conjunction with safety mats to protect operators and maintenance staff from injury during cell operation. Images of the guarding are shown in Figures 18 and 19 below above and the images below.

Figure 18

Figure 19

4.11 Current system Operation

The points below describe the current process of scribing bodies at NCMC utilising the equipment and technology described in the sections above:

- As the sides enter the scribing room their tags are scanned and details including carcase number, cut specifications, breed and weight are entered into the NCMC hosted SQL Server Database for the scribing system to retrieve when required.
- The first side enters the rotator and is rotated if required, it is then transferred out of the rotator where it waits for the second side to complete the same.
- Once both sides have passed through the rotator they are conveyed towards the backing boards. The first side travels all the way to Backing Board 2, the second side stops at Backing Board 1.
- Once the carcase is positioned in front of Backing Board 1 a low resolution greyscale image is taken of the carcase with the Cognex camera to obtain the silhouette required to determine clamp position. Once the image has been taken the backing board moves forward and the clamps move to position. Once the board is fully forward the clamps close with the side supported by the Backing Board..
- With the side clamped to the board a high resolution colour image of the side is taken and this image is displayed on the screen in the control room. Along with this image details of the

proposed cut specification for the side (based on the information scanned into the system as the carcase entered the room) are displayed on the screen. Approximately 80 cut specifications have been entered into the system and the system selects one based on the information scanned in as the side enters the room. If the scanned in cut specification does not exist on the scribing system the operator has the ability to create it for future use or just to temporarily select the required cuts and associated settings.

- The information displayed details the specific cuts to be made and the angle and depth of these cuts. At this point the operator has the opportunity to add or remove cuts as well as change cut depth and angle. Once the operator is happy with this information they proceed to mark the scribe marks on the screen. As soon as the operator commences placing the scribe marks the laser scanner scans the side to gather the 3^{rd} dimension information. When the operator is complete they accept the marks on the screen and the information is transferred to the robot and the robot begins scribing the side.

- While the mark up of the side on Backing Board 1 has been taking place the side on Backing Board 2 has been scanned for its silhouette image, the backing board has moved into position and the side has been clamped. As soon as the operator accepts the scribe marks for Backing Board 1, the image of the side in front of Backing Board 2 appears on the screen along with the cut specification details. The operator proceeds to mark this image up just as for Backing Board 1.

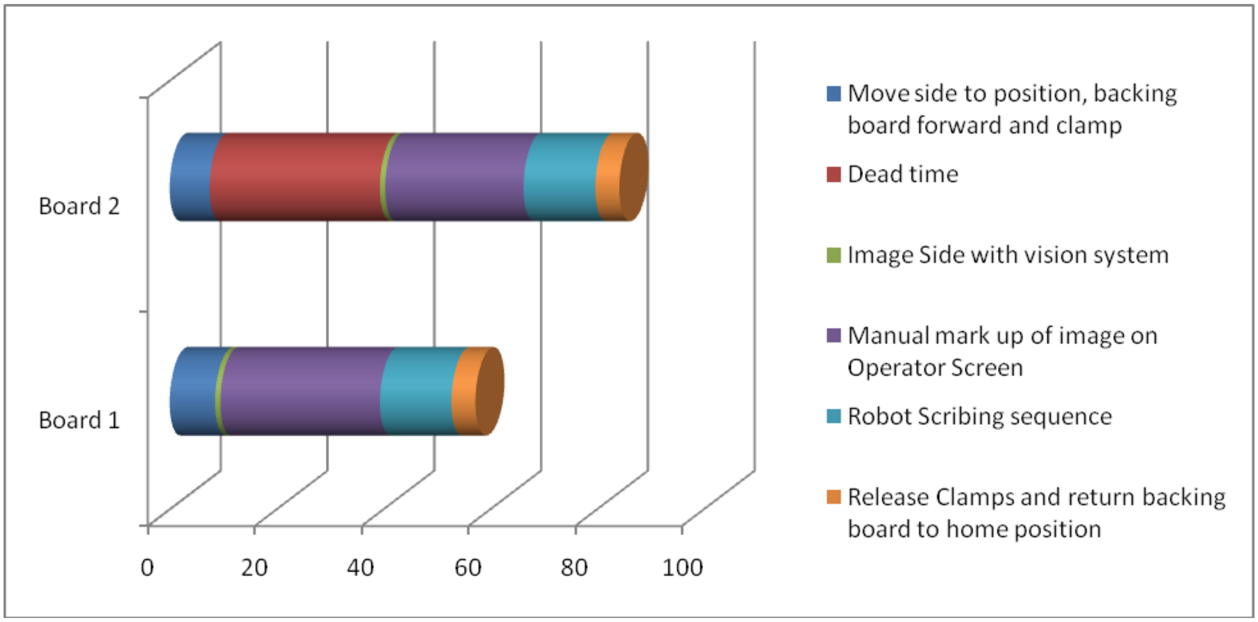
- When scribing of the side at Backing Board 1 is complete, the robot moves to begin scribing the side in front of Backing Board 2, the clamps are released on Backing Board 1, the board retracts and the side moves along the Transport Rail towards the exit of the cell.

- While scribing on Backing Board 1 has been taking place the next two sides have been indexed through the rotator, once the space in front of Backing Board 1 is clear these sides are indexed to the Backing Boards. The first side moves to a position between Backing Board 1 and Backing Board 2, while the second carcase is positioned in front of Backing Board 1 and the process begins again. Once the robot has finished scribing original side at Backing Board 2 the side is indexed away and the side between the Backing Boards is indexed to position.

4.12 System Cycle time

The system cycle time chart as it currently stands is shown below:

Process	Board 1	Board 2
Move side to position, backing board forward and clamp	8.5	7.5
Dead time	0	31.9
Image Side with vision system	1	1
Manual mark up of image on Operator Screen	29.9	25.9
Robot Scribing sequence	13.4	13.4
Release Clamps and return backing board to home position	4.5	4.5
Total		84.2



It can be seen from this that the system in its current state is capable of scribing approximately 43 bodies per hour or approximately 342 bodies in an eight hour shift..

5 Success in Achieving Objectives

To the extent that the project has 'developed, trialled and demonstrated an automatic beef scribing process' the objective of this project has been achieved. However there is still more work to be done to enable this system to become a viable production system. Recommendations as to possible improvements/development are included in Section 7 below.

6 Impact on Meat and Livestock Industry – now & in five years time

As the system currently stands it would not be suitable for a high volume production environment. This is largely due to the physical location of the system and the restrictions that this poses on the ability to process large volumes. However with further development it is felt that this system could have significant impact on the industry. The cost benefit to install a commercial beef scriber for a processor will be in terms of labour reduction, suppression of OH&S claims related with the task, operational improvements, boning room efficiencies and Yield gains achievable.

The industries recent inclination to participate in robotic developments shows among others the current industry trend towards automation, fuelled by more acute shortages in labour availability, which will likely get worse in the future.

Based upon a two shift operation beef processing plant an automated Beef Scribing System will replace 2-3 skilled saw operators per working shift.

This preliminary "DRAFT" cost benefit analysis "CBA" for a commercial Beef Scriber System indicates the following based upon cost estimates, all known process data, historical data from previous installations and taking into consideration all known or conservatively estimated Costs, Losses Gains & Savings.

Key Assumptions:

- Labour Savings per year = $265,341
- Nett yield gain per year = $570,947

POTENTIAL COST BENEFIT – COMMERCIAL SYSTEM		
Gross Benefit Per Head	*Over Year 1*	**$0.69**
Nett Benefit Per Head	*Over 10 Years*	**$0.38**
Net Present Value	*NPV*	**$4,567,780**
Profitability Index	*PI*	**4.86**
Payback time in years		**1.57**
Internal Rate of Return	*ROPC or IRR*	**69.15%**

7 Conclusions and Recommendations

This project has proven that Robotic Beef Scribing is possible and definitely has the potential to have an impact on the Meat and Livestock Industry. There are, however, a number of improvements that could be made to the current system that would undoubtly improve the results currently being achieved. The set up of the system in a purpose built room, would allow the following modifications and improvements to be made:

- The layout of the system to be improved and hence allow the transport rails to be designed to allow more efficient transport of the sides into and out of the room decreasing the amount of labour that is currently required.
- Replacement of the stationary backing boards with a moving backing board. This would allow the side to be supported along the length of the scribing zone and eliminate the need for clamping. It would also increase the through put of the system by reducing the speed restrictions due to swinging carcases and would eliminate the wasted time positioning backing boards. Development of a moving backing board would required design and trials to be conducted and probably require more space than is available in the existing chiller.
- Imaging of the sides with the Cognex camera and laser with possible use of more advanced 3D camera systems at a station prior to presentation to the scribing position. This would allow scribe mark processing on the fly and quicker scribing of the side once presented to the robot.
- Increased roof height to allow a better rail transport system and processing of larger carcases.
- Modifications to the rotator to allow processing of larger carcases
- Further development of Automatic scribe mark placement. It is felt that with further development in this area greater accuracy in automatically placing the scribe marks could be achieved.
- An Improved sterilisation system
- Installation of dual cutting robots to allow for the required processing speed of 2000 head/day