final report

Project Code: P.PIP.0164

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Date published: January 2011

PUBLISHED BY
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Automated Beef Hock Cutter

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Abstract

This project aimed to successfully automate the beef hock cutting process using suitable sensing technology, a robot and a cutting tool. The sensing aspect of the system was to build off previous work done by Food Science Australia using thermal imaging. The current manual process requires the use of a heavy and powerful hydraulic tool which poses significant OH&S risks. The main motivation for the project thus lay in the potential to increase safety in the industry. There were also expected financial benefits with respect to labour and training. The system has been designed, trialled, installed and commissioned at Swift's Dinmore facility and, in spite of the large number of constraints placed on the system, is operating in full production, completely autonomously with a success rate of over 97%. Although significant challenges were faced, the project has thus proven that it is possible to successfully automate the task of beef hock cutting.

Executive Summary

The red meat industry has been identified as an industry with significant potential for automation of tasks. One such task is the beef hock cutting operation. There reasons for this include that it is highly repetitive in nature; it has been achieved in other meat industries; it is performed to an unchanging specification; and there is some leniency in accuracy.

A major benefit in successfully automating the Beef Hock Cutting task is the positive impact it has on OH&S considerations for the industry. When performed manually, this task requires the use of a heavy and powerful hydraulically-operated cutting tool. Such a tool requires significant effort to manoeuvre effectively, even with assisting mechanisms such as chains and wires. This adds to the significant potential for amputation or serious injury such a tool possesses.

Another key motivator is related to labour replacement, especially in the case of high-volume processing facilities, such as Swift. It is expected the system could bring savings of over $50,000 per shift per year. On top of this, savings relating to training can be expected due to the high-turnover nature of the industry. There are also expected benefits relating to increased production, minimization of waste and higher levels of hygiene.

The key objective for the project was thus to develop and trial an automated beef hock cutting system and prove its ability to perform in production. This was to be achieved through the integration of three key elements: sensing technology, robotics and a cutting mechanism.

Such a system would be required to operate in an autonomous manner, with an operator only required to start or stop the system or change the cut specification if required. It would have to operate effectively for continuous line speeds up to 240 head per hour and show the ability to process all sizes and breeds of beef encountered at the facility. It is expected that the system be able to operate under all temperatures experienced at the plant and be able to withstand the demanding conditions endured during chemical wash down. Finally, there were strict requirements placed on the cell's footprint as well as hygiene.

Any autonomous system can be thought of as comprising three main sub-systems: sensing, control and actuation. The sensing sub-system for this project was to build off the research done by Food Science Australia regarding the automation of the beef hock cutting process. A thermal imaging camera would thus be used to try and locate the ideal cutting position along the leg of the carcase. A stereographic camera would also be needed to provide 3D information of the carcase, allowing it to be located in space.

The control sub-system would consist of a PC, PLC and robot controller. The PC would be utilised to process the image data and obtain the correct cut location and orientation in 3D space for the current carcase. The robot controller would direct the robot's movements during the cut and sterilisation cycles while the PLC would provide overall timing and control for the system.

Finally, the actuation of the system of the system would be primarily achieved through an industrial robot and hydraulic cutting tool to achieve the actual task of cutting the hock off.

The project involved extensive trialling and acceptance testing before being installed in mid-2009. The system is now running in production, cutting with a success rate of over 97%. Due to the R&D nature of the project however, a number of unforeseen issues arose during the commissioning process which had to be dealt with to get the system to this point.

One of the key challenges faced was that of carcase stabilisation and presentation. In order to maximize the chance of creating a reliable system, it is required that the carcases are presented as consistently as possible and that they remain stable during their transition through the system's cell. The higher the level of variation that occurs, the higher the chance of either the visioning process failing or the robot missing the hock. Addressing this issue required a number of modifications to the initial carcase stabilisation plan as well as a number of changes to the location of the cameras within

the cell. The latter of these also brought about significant changes to the vision program due to re-tuning of tools and the requirements of new mathematics for cut position calculations.

Other issues encountered included: the positioning of the wash tank; lighting; the requirement for a faster and more effective robot recovery routine; missed cuts; and cut orientation.

Despite the challenges faced, the system is now running in fully production, as aforementioned. The success rate of over 97% is a significant improvement over that initially achieved at the beginning of the commissioning process. The system has shown no issues with cycle time, showing its ability to operate under even the fastest chain speeds encountered. The training of electricians, fitters and operators has also been conducted.

Although there is still a relatively minor issue to be addressed, this being ongoing issue regarding the robustness of the robot bag, it can be seen from current progress that the beef hock cutting process is certainly able to be successfully automated, even in a challenging environment such as that encountered at Swift's Dinmore plant.

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1 Background

The 2007 Technology European tour with MLA and various Australian Processors served, among other things, to illustrate how current technology can deliver clever solutions to automate manual tasks. An example of this is Beef Hock Cutting. This is a typical case where the task is simple enough to be easily replicated by an automated system. The hock cutting process can be seen as an ideal candidate for automation as:

- it is a repetitive task;
- it has been achieved in other meat industries;
- it is performed to an unchanging specification; and
- there is some leniency in accuracy.

A major benefit of successful automation is the positive impact on some of the critical industry OH&S. Prior to this project the beef hock cutting operation is performed manually by an operator with a heavy powerful hydraulic tool. The mere use of such a tool represents an OH&S issue. Even with aids like hanging cables and springs the physical effort needed to operate the tool results in potential for serious operator injuries such as amputations.

Figure 1 - Manual Hock Cutting Process

The beef processors who participated in the mentioned technology tour (Northern Co-op Meat company and AMH), witnessed how a solution, based on a robotic arm guided by a sensing laser 3D profiling system, managed to cut pig hocks at high processing speeds under normal operational conditions. Both processors expressed their interest in a potential solution for beef hock cutting, and AMH offered to participate in a PIP project to progress towards an operational solution for beef, which should eliminate the human component of the task, and reduce the labour count in one unit per shift.

The high production volume of AMH justifies the investment more easily than in other cases, given that they operate three shifts, and this system will bring labour savings over $50,000 per shift per year (over $150,000 per year for AMH). However, AMH’s recent inclination to participate in robotic developments shows the trend the industry is following towards further automation, fuelled by more acute shortages in labour supply, which will likely get worse in the future.

1.1 Experimentation/Investigation work to date

FSA has designed and trialled a sensing concept for the hock cutting process (see PRTEC.042, Milestone 3 report), based on thermography, but other technologies developed in that project like laser 3d profiling are available too. MAR has a close working relationship with FSA and has actively engaged FSA throughout the trials of the prototype. FSA has sent the reports and videos of what has been done to date and has offered their support in the project when required by MAR.
The sensing system developed for the beef hock cutting process can successfully locate features and a referenced cutting position along carcase legs. The features being identified include the hoof tip, leg angle, hoof-to-hide line and dew claw location. This sensing system can successfully establish a cutting point relative to the tip of the hoof, or at a position relative to the dew claws.

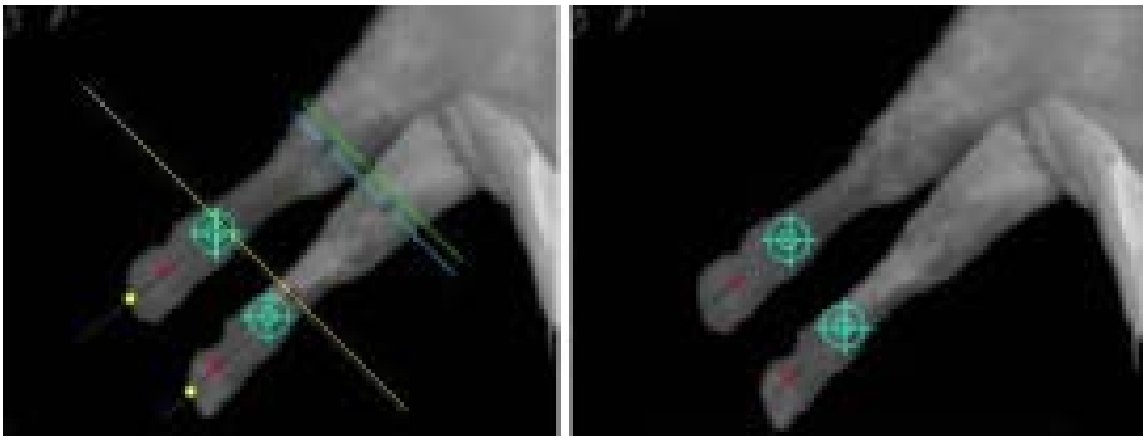

Figure 2 – Sensing images from FAS PRTEC.042 Milestone 3 Report

The approach as a whole is similar to the one developed by BANSS in Europe to automate pig hock cutting, where an integration of sensing, robotic arm and conventional cutting tool is performing the task satisfactorily and economically without human intervention. The differences between the two species, pork and beef, do not allow the direct transfer of that technology to cut beef hocks, although the solution is not radically different. Given that no other company in the world is working now in this technology for beef, and FSA's sensing developments described above, the fastest way to take the technology to market and make the Australian industry benefit from it, goes along with MLA supporting this project.

2 Project Objectives

The objective of this project is to integrate the three main elements

- Sensing technology
- Robotic arm (commercial equipment)
- Cutting tool (conventional tool)

to substitute a human operator by an automated system doing the same hock cutting task. Additionally, the project includes the design and manufacturing of a proper stabilisation structure, to keep the carcase in a consistent position while it moves on the chain, allowing the correct sensing and hock cutting. In this case, the initial concept envisaged consists of extending the bar used for stimulation in AMH's Dinmore plant to hold the carcase in place and support it in a consistent position while the measurements are taken and the cuts performed. The system must be fast enough to allow the cut of both hocks with only one robotic arm at the maximum chain speed of 240 head/hour.

3 Methodology

The descriptions in this section detail the initial planned approach and scope of supply to the project. As will be seen in section 4 various circumstances lead to modifications in design scope of work and operations.

3.1 System Principles and Design

System is to automate beef foreleg hock cutting (dirty), through the integration of a conventional cutting tool, modern sensing equipment and a robotic arm to perform the task satisfactorily and economically without human intervention.

- The system will be integrated to fit within the existing line without obstruction to existing operations or the movements of staff.

- Existing operations on the floor must be relocated down the line, indexed by one operation station to optimize the position of the robotic hock cutter allowing the use of existing and newly extended stabilization rails from the stimulator.

- System operate in the following format;
  - Beef Carcases will enter the robotic hock cutting cell from the stimulator hanging by one rear leg from the chain conveyor with front legs hanging down at an angle.
  - The bodies will be stabilized and rotation inhibited by use of a top rail extension to the stimulator promoting adequate stabilization and positioning for sensing and the hock cutting process. Further stabilization methods will be required and implemented in a step by step procedure as indicated later in this section.
  - Thermal imaging will be used to locate features and a reference cutting position along carcase legs.
  - The robot will in turn be used to operate the hock cutter to cut at the determined location.
  - The carcase body will be tracked using an encoder on the overhead chain conveyor with feedback to the robot control system.
  - Cut hocks will be dispensed into the hock removal chute and the Hock cutter will be sterilized between cuts as required.
  - If two carcases come through the stimulator together or the body is not orientated prior to the stimulator the hock cutting system may bypass these carcases for operation.

- Sterilization of the hock cutter to be completed after each body, i.e. after the two hocks have been cut from each carcase. Sterilization is to include all carcase contact points and meet the AQIS sterilization specifications.

- The system is to operate in a moist wash down area environment, typically +20ºC to 28ºC and will be adequately protected against wash down procedures and chemicals. All surfaces and materials will be such to allow for easy cleaning and maintenance.
- System Rates - The system will be setup to cut both hocks and sterilize tool with only one robotic arm at the maximum chain speed of 240 head/hour.

3.2 System Integration Principles and Scope of Work

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

3.2.1 Robot System

One Kuka KR60-3, six axes industrial Robot System consisting of:

- Kuka K60-3 six axes industrial Robot System with 60kg payload capacity and 2033mm reach.
- Kuka Robot Controller with IP54 rating, the highest level available in any controller.
- Controller to be mounted and structurally supported within in the roof space above the operational area
- Connection cables from robot manipulator to robot controllers
- Kuka Control Pendants with Colour PC Screen.
- Kuka Robot Base Software
- Kuka Conveyor Tracking Software and Conveyor Tracking Synchronization Module
- CDROM Drive and Floppy Disk Drive
- Interface to PLC system
- Kuka controller cooling unit for ambient air +20ºC - 55ºC
- All connections to the robot manipulator will be by plug / socket
- All connections to the robot controller will be by plug / socket

3.2.2 Robot Base Frame

One Robot Base Frame to elevate & support manipulator in the inverted position

- Stainless steel construction with platform to mount the robot manipulator
- Stainless frame to withstand wash down environment and sterilization standards
- Chemset fixtures to floor surface

3.2.3 Robot Bag

One Robot Protective Wash down Cover/Bag System;

- The arm of the robot is covered by a protective bag, sealed at the robot wrist.
- Specifically designed to suit application and manipulator movements
- The bag and enclosure sections are designed for easy removal for access to the robot manipulator.
- Wash down protective covers for the robot system
- Ducted fan for air supply to maintain positive pressure in the wash down cover

3.2.4 Line Tracking Chain Encoder

One Encoder fitted to the overhead chain system for tracking movement of carcase

- Interfaced to the Kuka robot controllers conveyor tracking synchronisation module
- Chain encoder, conduits and cables to robot control system
- Mechanics to fit to encoder to chain

3.2.5 One Hock Cutter Tooling Set

One Beef Hock Cutter adapted for robotic mounting (Eg Jarvis 30CL), Hock cutter will include the following equipment for disposal of Hock to removal chute:

- Integrated clamp used for stabilisation
- Integrated hock collection bucket, used if sufficient grip is not obtained when cutting dew claws only.
- The tooling will have integrated laser distance sensing and a mechanically operated proximity sensor for detection of hock in the third plane after thermal image detection for increased accuracy and cycle time.
- System to utilise existing Pneumatic and hydraulic drive system for hock cutter
- The hock cutter fixes to the robot roll face adaptor plate, with dowel pin location guides for repeatable relocation.
- All electrical connections to the tooling will be by plug/socket
- All pneumatic and hydraulic connections and fixed piping and flexible hoses to the tooling included.

3.2.6 Carcase Body Stabilization and Orientation Equipment

- The robotic hock system requires each carcase to maintain a relatively consistent orientation and remain stable for operations.
- The existing stimulator system will be extended by up to 3M to maintain this orientation and stability of the carcase,
- The extent of these modifications cannot be completely defined until equipment is put in place in a staged process to minimize work required to stabilize the carcase.
- Planned orientation and stabilization equipment includes;
- Carcase Stabilization Stage 1 - Top rail round bar extension with tapered exit as per current stimulator system
- Carcase Stabilization Stage 2 - Fore Leg deflector, required to re-orientate carcase and lower fore leg below bar after the stimulation process and to provide consistent leg positioning for hock cutting.
- Carcase Stabilization Stage 3 - Bottom rail round bar extension with tapered exit as per current stimulator system, the bottom rail maybe mounted at a different height from the current bottom rail.
- Carcase Stabilization Stage 3 - Head deflector bar to deflect large bulls head away from the safety matt should the bull be large enough where it’s head hits the floor
- All modifications will be stainless steel and similar construction to existing system
- Construction, structural support work and bracing is included
- Structural engineers to review any planned modifications and extensions.

3.2.7 Sterilisation System

- The Hock Cutter sterilization system cleans the hock cutter and any other contact surface between carcases or every second hock cut.
- The sterilisation basin is constructed from stainless steel and designed for the hock cutter similar to the existing system used in the manual process.

- Connection of water supply to the sterilisation system and removal of waste shall be done as per current manual process.

3.2.8 Hock Removal Chute and Ducting

- The hock removal chute, used for disposal of cut hocks via the robot will be Stainless steel in construction and be specifically profiled to suit robot operations
- Integrated sensing for detection of hock in the third plane after thermal image detection.
- Hocks will be disposed off in the chute where they will fall through a fitted duct to the hock removal conveyor.
- Includes concrete slab floor modifications required for chute/ducting.

3.2.9 Removal and Re-Installation of the existing workstation equipment

- Existing workstations must be relocated and indexed one operation station further down the production line to make available space for the robotic Hock Cutting System.
- The Robotic Hock cutter will be located at the first available space after the Stimulation Rails.
- One of the stations to be relocated is the existing manual Hock Cutting operation which will remain an operational station to be used should the robotic Hock Cutter be out of service and/or unable to perform hock cutting for a specific reason.
- Includes disconnection and re-connection of services
- Includes required concrete slab floor modifications, repairs and epoxy repairs.

3.2.10 Panel PC

One (1) Panel PC ”HMI” and Electrical Controls with;

- The hock cutter robotic cell will include one Panel PC “HMI” with incorporated electrical controls and safety systems.
- One Industrial Panel PC and HMI “Human Machine Interface” for system control and camera system interfacing
- 15” Touch screen display
- Ethernet Hub and Interface
- Mounted within mounted in a sealed enclosure in a suitable location near the Robot.
- Electrical cabinet wiring, installation includes all Isolation, Circuit Protection, Control
- Relays, Termination etc.
- Safety System interfacing.
- Interfacing to Thermal Imaging Camera
- The HMI Operator interface used to control the robot system and perform camera setup operations will be located at the entrance to the robot cell and is customised by MAR to suit system with operations to include
- Thermal Imaging Setup and display
- Operator selection from Dew Claws to Full Hock
- System control and Maintenance
- Production and System Status

- A VPN connection will be setup with local Ethernet cabled back to AMH Slaughter line control room.
- System programming and commissioning
- Installation and documentation

3.2.11 Thermal Image Camera

- The thermal image camera will be used for the beef hock cutting process to locate features and reference cutting position along carcase legs.
- The features to be identified include the hoof tip, leg angle, hoof-to-hide line and dew claw location. This sensing system will establish a two dimensional cutting point relative to the tip of the hoof, or at a position relative to the dew claws.
- The tooling will have integrated laser distance sensing and a mechanically operated proximity sensor for detection of hock in the third plane after thermal image detection for increased accuracy and cycle time.
- The camera system will be interfaced with the control system PC where analysis software will be used and interfaced with the robot controller.
- The camera will be housed in wash down proof enclosure

3.2.12 Safety System and Guarding

- The robot manipulator is surrounded by safety panels that enclose the robot from 2200mm above floor level down to 300mm above floor level.
- Guarding will consist of stainless steel posts, with silicone coated polycarbonate viewing panels.
- Additional guarding will be mounted on the opposite side of the line from the robot preventing access to the robot cell from behind.
- An angled stainless steel guard will be fitted to the guard system at the raised slab level preventing access to the robot cell from underneath. A gap between the guard and the raised slab will allow for ease of cleaning,
- A safety matt will be located on the RH side of the cell where the carcase exits the hock cutting area. This safety matt will prevent access into the cell working area. A head deflection rail will be fitted near the matt to prevent the head of large bulls activating the safety mat.
- One (1) Access gates fitted with Fortress style captive key lock system, interfaced with the robot controllers' servo system. Provides for ease of access into cell for maintenance and cleaning,
- Access within the cell area is controlled via operator controlled actuators "Fortress style captive key lock system" which disable the safety doors allowing access and in turn disabling the robot from operating
- Emergency Stop push buttons will be located at each personnel access areas.
- Safety of the system will be controlled through Pilz safety relay system.
- Access and Alarm signalling system together with actuators are located at the control points of each designated access area.
- Cabling, conduits and terminations from the light curtains to the control system

- All conduits to be fully enclosed stainless steel with stainless steel dropper used where required

3.2.13 System Programming and Commissioning

- System programming of the camera and robot system to suit hock cutting application.
- Programming of the Human Machine operator interface (PC Panel) for the configuration of the robot system, thermo camera, electrics and pneumatics, with facilities for the manual control of some components of the system for servicing and testing.
- System commissioning of the robot system.

3.2.14 System Safety Audit

- A Safety Audit and Risk Assessment for the system will be provided for discussion and action.
- Consists of safety audit prepared by Machinery Automation & Robotics Pty Ltd and site meetings with client to ensure that the system meets all current safety requirements.

3.2.15 Pre –delivery and Factory Acceptance Test

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

3.2.16 Installation of the System

- System delivery to your facility in Dinmore QLD, and installation during non production time.
- On-Site installation and wiring of all machinery and equipment is managed by Machinery Automation & Robotics’ Project Manager, who coordinates this installation of the system components.
- Includes all fixings and equipment required to complete installation,
- Manually operated pallet jacks and lifting equipment to be used for placing robot system
- Into position.

3.2.17 Commissioning of Supplied Equipment Components

- Commissioning of all installed equipment to be managed by Machinery Automation & Robotics’ Project Manager, who coordinates with the appropriate personnel to ensure all commissioning requirements are completed on schedule.
- Dedicated MAR engineers will be committed during the commissioning period.
- Commissioning incorporates complete test and debug for all supplied components of the robot system

3.2.18 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 quotation.

3.2.19 Training

- To familiarise the operators in the program structure and system control, one 2 day training session will be held at Machinery Automation & Robotics' facility.
- It is envisaged that this training course would be held at the time of the Factory
- Acceptance Test. Alternatively this training session can be held at the customer's site if preferred.
- Training will be split between operator training, and the more advanced maintenance training. To ensure that the operators fully understand the operations of the robot system, 3 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 staff fully understand the operations of the robot system, additional on site training sessions of 4 hours duration is included to train the maintenance technicians.

3.2.20 Documentation and Operation Manuals

- Two sets of documentation including Electrical Drawings, System operation procedures,
- Safety Audit and Risk Assessments and Operation manuals will be provided upon commissioning.
- System Videos, reports and documentation detailing the system, its components and operational procedure to be provided by MAR to MLA for industry dissemination and promotional purposes

3.3 System Operation

3.3.1 System Start-up

- The system must be first be powered on by turning the Main Switch on the main control cabinet. The robot controller main switch must also be switched on as well as the computer in the computer panel and the HMI screen in the operator panel. Ordinarily, these components are always powered on unless maintenance is being performed.
- Once the computer and robot controller have booted up and the HMI program has loaded, the system is ready to be started up.
- Ensure all points of safety are clear and reset the safety by holding the blue reset button.
- To start the cycle, the green 'Start Cycle' button must be pressed and held until it becomes solid. This will cause the robot to perform a rinse routine and move into its waiting position. The system is now in production.

3.3.2 Automated Cycle

- Once a carcase reaches the first trigger, the conveyor tracking will be activated in the robot and the two cameras will acquire images.
- The vision program then identifies the cut position and orientation for the robot.
- The cut coordinates are sent to the robot which moves the tool into position and tracks along with the conveyor. Once in position, the cutting tool will close. The pneumatic clamp will also close.
- Once the cut has been completed, the cutting tool will open and the robot will move to the hock chute.
- When the robot is over the hock chute, the pneumatic clamp will release the hock into the chute.
- The robot moves into its waiting position
- Once the carcase reaches the second trigger, the process will be repeated.
- Once the second hock has been sent down the hock chute, the robot will move the cutter into the wash tank and a sterilisation cycle will be performed.
- The robot moves into its waiting position

3.3.3 Shutdown cycle

- Press the red ‘cycle stop’ button. The robot will finish its current operation before moving into its park position. The system is now out of production.

4 Results and Discussion

4.1 Introduction

MAR have worked closely with Swift since the commencement of the project to develop the Hock Cutting System that is being used in production today. The project has faced a number of challenges throughout its life that have caused the plan described in Section 3 to be varied. These challenges along with the projects achievements are described in the sections below.
The following table details the changes from plan that occurred throughout the project:

Challenge Faced	Planned Approach	Variation
Carcase Stabilisation	Stabilisation Bars. Leg guide plate.	Removal of front bar. Modification of back bar. Conveyor installed.
Camera Positioning and Acquisition	Cameras mounted on pole just off walkway, upstream of cell. Two images from same position.	Cameras mounted up high within cell. Camera box rotates between two positions for each image. New math's required for cut coordinates. Large bore cylinder installed.
Wash tank position	-	Wash tank moved. Chimney installed.
Lighting	Fluorescent lighting to be used.	Spotlights added
Missed Cuts	Original cutting jaws used with tool.	Use sheep head cutting jaws with wider opening. Design improved.
Isolation for robot movement.	-	Isolator connected to robot superior stop installed.
Isolation of hydraulic power pack.	-	Power for power pack run through safety circuit.
Splits in robot sock.	-	Bag repaired and replaced.
Robot recovery.	One recovery based on joint movement.	Two separate recovery routines based on whether in a cut.

Cut orientation.	Cutting perpendicular to leg direction.	Cutting at 45^{o} off leg direction.
Blade cleanliness.	Wash tank with 4 rows in X-configuration of 3 nozzles .	Robot program modified to improve cleaning
Hock tool mounting.	Hock tool is mounted to frame using two mounting screws and a saddle.	The saddle is replaced by two mounted brackets which are used to clamp the tool. Redesign of tooling to improve robustness.

4.2 Technical Development Carcase Stabilisation Project

As part of a technical development project that MAR and AMPC had running at the time significant R & D work was performed on Swifts site at Dinmore in relation to carcase stabilisation. Stabilisation of the carcase was going to be significant to the success of the Hock Cutting project since the more stable the carcase the less variability there would be in processing the vision data and more accurate the cutting of the Hocks. Ideally, the carcases should be sitting with both hocks pointing directly back along the line of the chain (i.e. not rotated too far away or towards the robot) with minimal swinging in any direction. This initial stabilisation work was performed throughout 2008 and involved manufacturing and installing extensions to the existing guide rails on site. The Figures below show these extensions.

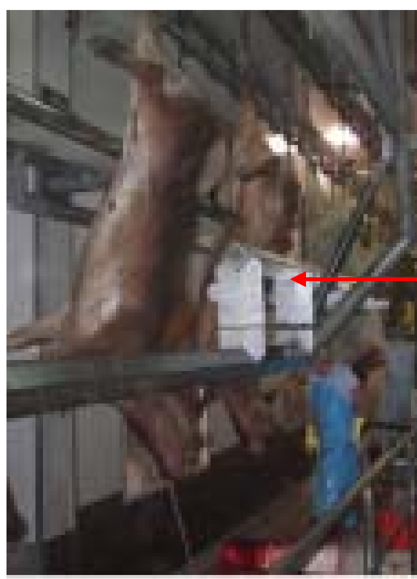

Figure 3 – Bottom Rail Extension

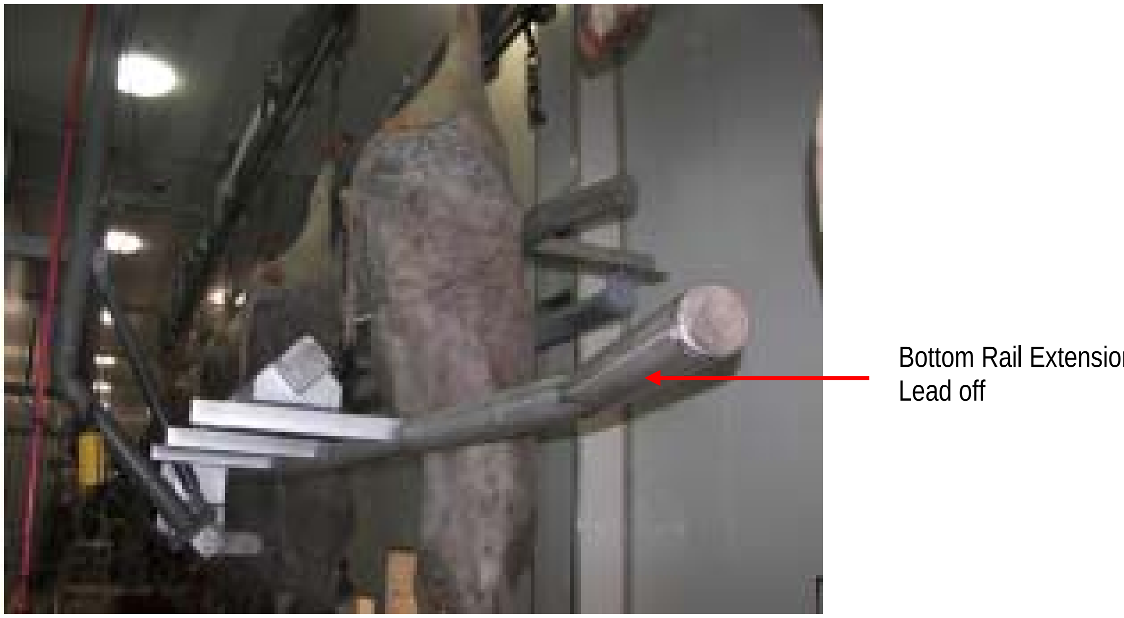

Figure 4 – Bottom Rail Extension Lead off

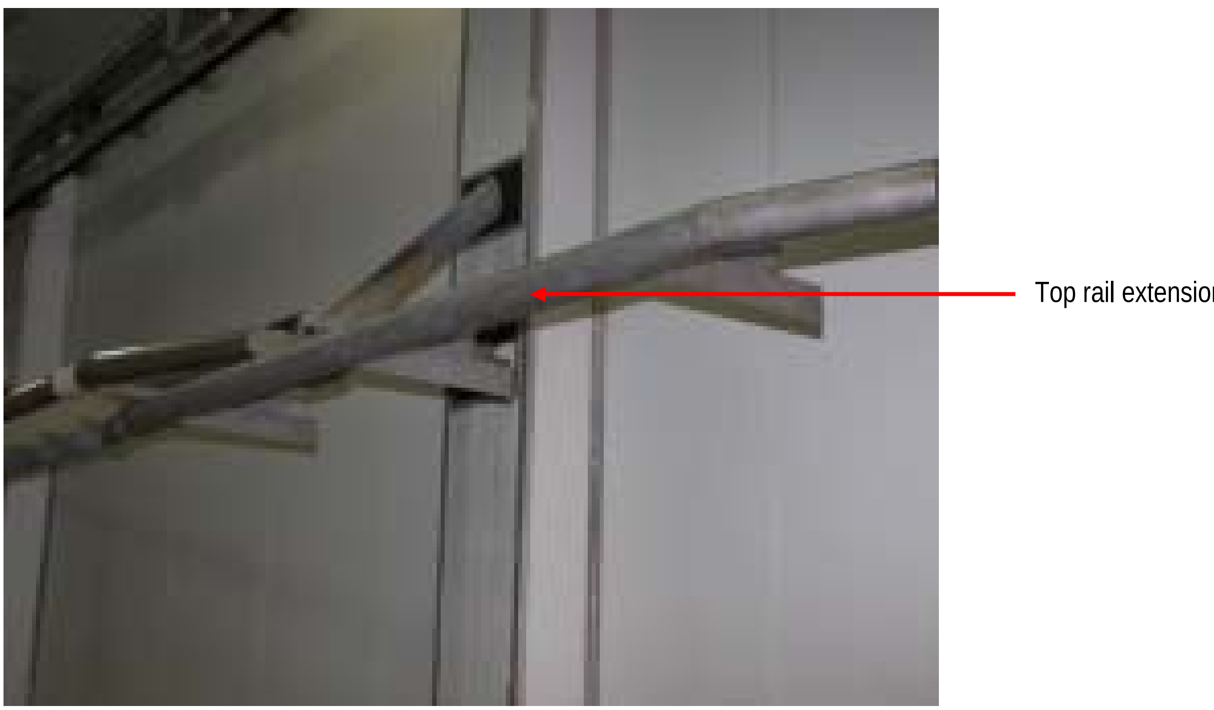

Figure 5 – Top Rail Extension

These extensions assisted, however as the project progressed it became evident that the carcase was inclined to roll along the bar making it difficult for the vision system to obtain a reliable image of the Hocks.

To address this, plates were added to the guide bars in an attempt to stop the carcase from rolling, these plates are shown in the figure below.

Figure 6 – Guide Plates

These guide plates were successful in stopping the rolling of the carcase, however it induced a swing to the travel of the carcases as the rump of the carcase ‘stuck’ to the plates and caused a jerky travel of the carcase along the plates.

At this point the guide plates were replaced with a motorized conveyor that was synchronized with the conveyor speed, as shown below. This conveyor allowed the rump of the carcase to be supported by this conveyor but also conveyed in the direction of chain travel with minimal swinging or rolling of the carcase.

Figure 7 – Motorized Conveyor

4.3 Vision System Development

Using the concept of a thermal camera for detecting Hock location, as trialled by Food Science Australia, MAR conducted extensive tests onsite at Swift. The reason for further pursuing the thermal imaging path as opposed to traditional machine vision was due to the wide variety in size, shape and colour experienced with carcases and it was felt that while cold hocks are occasionally encountered, for the most part the thermal presentation of a hock remained relatively consistent and would provide the most reliable method of detection. The work completed by FSA concluded that it was possible to identify the hoof tip, leg angle, hoof-to-hide line and dew claw location in order to ascertain a cut position. It also established that there is an expected time frame of up to 30-45mins after knocking in which the visioning operation must occur. Outside of this window, the temperature of the hock may drop to the point that it cannot successfully be processed using a thermal image. The thermal camera used is shown below:

Figure 8 – Flir Thermo vision Camera A320G

The challenge that MAR experienced during trials was that it was very difficult to manipulate the carcases such that 100% of them were presented with their fore hocks perpendicular to the camera position. This was required to enable the thermal camera to accurately detect the position of the hocks. The images below show some of the variation in the orientation of the carcases:

Figure 9 – Hock orientation slightly away from the camera beam, this generally occurred on larger animals

Figure 10 – Hock orientation perpendicular to camera beam - Ideal

Figure 11 – Hock orientation towards camera beam – Generally happens on smaller animals

These different scenarios showed that while the thermal camera was able to detect the hocks in a 2D or X-Y frame it was unable to give any data in the 3rd dimension or Z frame and therefore lead to inaccuracies in correctly locating the hocks.

It was realized at this point that in order to accurately locate the hocks in 3D space a second sensing technology was needed to compliment the thermal camera. For this purpose two possibilities were identified:

a) Stereo vision

b) Laser profiling

Stereo vision was chosen as the preferred option due to the speed with which the image needed to be obtained and the fact that the carcase is attached to a moving chain making it difficult for a laser scanner to get an accurate scan.

The stereovision camera chosen is shown below:

Figure 12 – TYZX 3D Stereovision Camera

This camera was able to provide data that allowed the hocks to be located in the Z plane as well as the X – Y plane.

Trials with the stereovision camera showed that good quality data could be obtained, although positioning of the cameras and lighting of the area would have an impact.

Through initial trials the camera box was positioned upstream of the robot cell however during commissioning, it was found that the carcase was too far away when the second shot was taken leading to unreliable data. After experimenting with a number of positions the camera box is now mounted inside the cell above the robot. The cameras take an image of the first hock as the carcase comes into range, the camera box is then rotated by a pneumatic cylinder as the carcase moves along the rail before the second shot is taken.

The initial lighting selected for the project proved to be insufficient once it was evident that the stereo vision camera would be needed. As a result four additional spotlights were installed improve the quality of the stereo-imaging data. The figures below show the images obtained from the Thermal camera, the Stereo Vision camera as well as the final positioning of the lights and camera box in the cell.

Images from both cameras and images of the final lighting and camera setup are shown below:

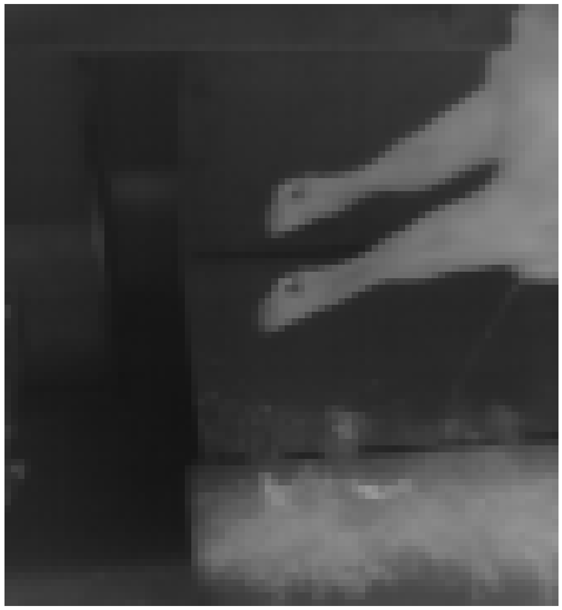

Figure 13 – Image from Thermal Camera

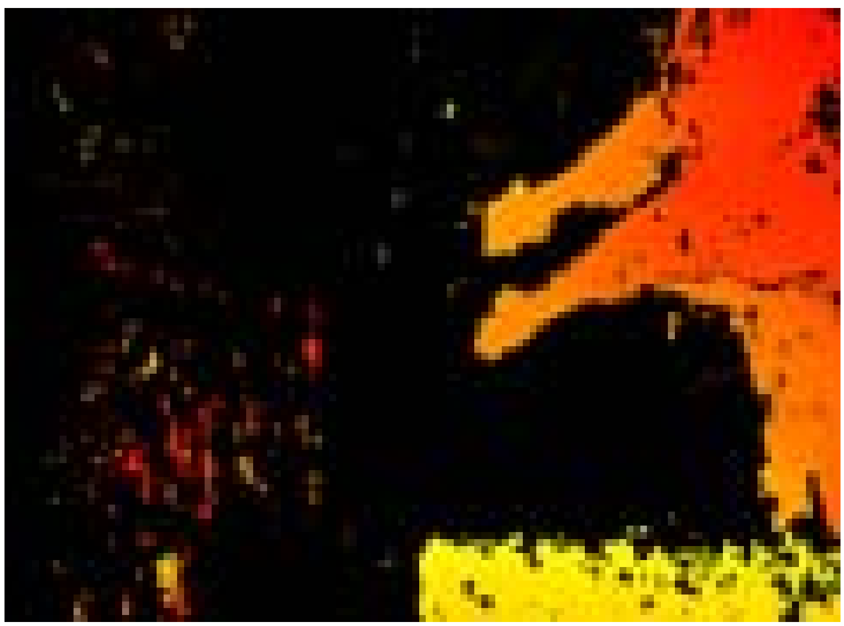

Figure 14 – Image from Sterovision Camera

Figure 15 – Final Lighting Setup

Figure 16 – Camera Box Position

4.4 Robot System

At the time of project commencement ABB released the IRB 4600 robot. This robot was selected in preference to the proposed Kuka robot since it was faster and smaller in size than the Kuka and meant that the robot could be mounted on the ground rather than mounted from structure above the cutting area.

The robot is protected from wash down conditions by a robot bag. Due to the complicated movements that the robot is required to make to correctly perform the task of cutting the Hocks there have been issues with wearing and splitting of the bag. The initial bag was replaced and the new one has had patches added to it to accommodate the required robot movements. Another bag will be provided that includes the extra bag portions as part of its initial manufacture.

Figure 17 – Robot Bag

The robot was programmed by MAR engineers using Robot Studio. This program was primarily required to direct the movement of the robot: through each cut; to drop the severed hocks; to perform the sterilisation routine; and to perform the recovery routine when a fault with the robot occurs. It was also required to control the actions of the cutter and clamp. Only minor changes to the robot code were required during commissioning.

4.5 Cutting Tool

The cutting tool underwent a number of design upgrades and modifications through the commissioning and initial production phases of the project. The cutting tool initially used for the system was a Jarvis 30CL-2 hydraulic hock cutter This is actuated using a hydraulic power pack and was attached to the robot roll face with a stainless steel frame. During the commissioning process, carcase swinging caused a significant number of cuts to be missed. In order to offset this issue, the existing jaws were replaced by a set of head-cutting jaws used for sheep processing. These had a wider opening and thus provided more flexibility in cut placement.
As commissioning progressed into production, it became evident that the frame supporting the tool was inadequate with the securing screws repeatedly working themselves loose over time and the hock gripping mechanism becoming loose causing the gripper to repeatedly drop hocks. This lead to the redesign of the tool and the new design is shown below.

Figure 18 – Cutter – Original Jaws

Figure 19 – Cutter – New Jaws

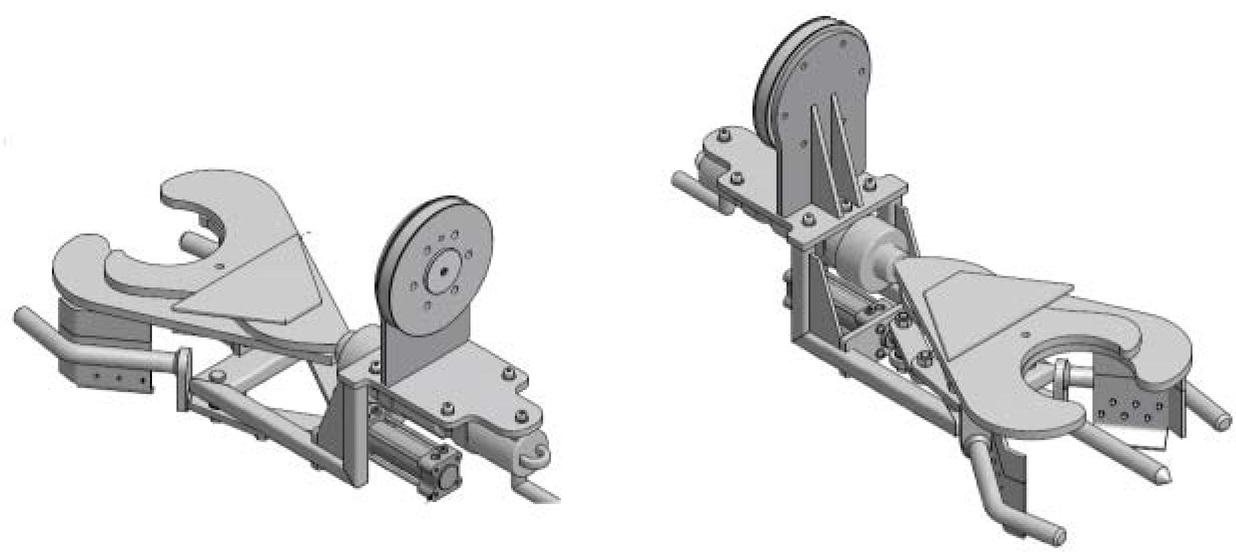

Figure 20 – Original Cutter Design

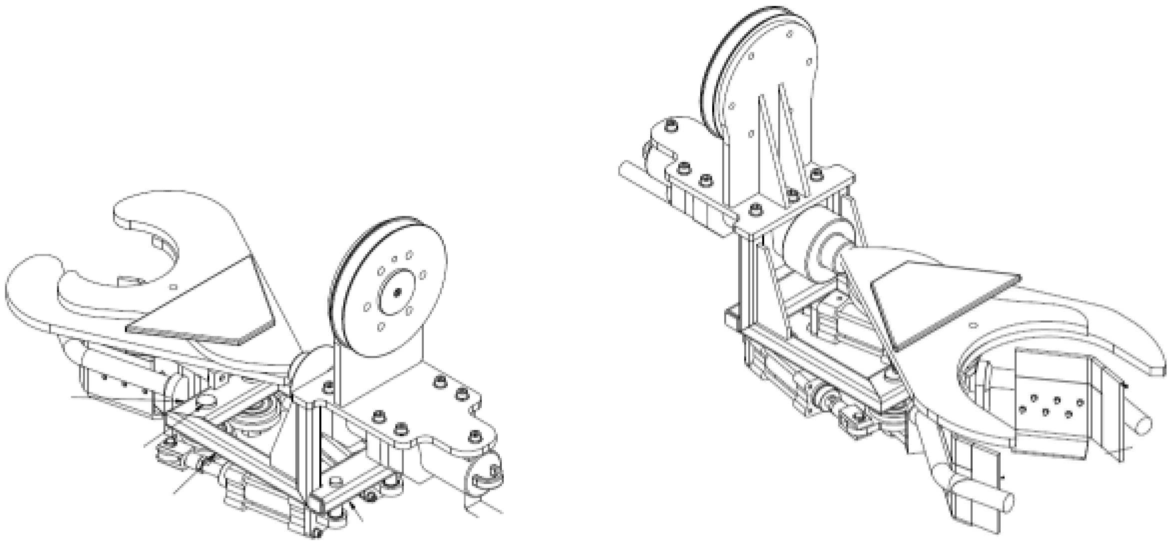

Figure 21 – New Cutter design, Note double cylinders for activating Hock Clamp, Larger Plates for Grabbing Hock and improved mounting of Jarvis Jaws

4.6 Sterilization

A wash-tank was designed for sterilisation of the blade. This tank currently houses four rows each containing three high pressure nozzles. The robot moves the tool into the tank where the nozzles spray the blades before the tool is retracted from the tank.
Issues arose during commissioning where, due to the commanded robot path, the robot collided with the tank. As a result, the location of the tank was shifted as far away from the line as practically possible. Since this move, no collisions with the tank have occurred during automatic operation.

Figure 22 – Original Wash tank Position

Figure 23 – New Wash tank Position

Moving the wash tank to its new position however meant that steam from the wash tank was interfering with the cameras causing inaccurate data to be processed and hocks not being cut. In order to address this issue, a chimney was installed to direct the bulk of the steam away from cameras.

Figure 24 – Chimney Circled

Recent modifications made to the robot program have overcome what had been an ongoing issue of the ability to adequately clean the cutting blades. The modifications have meant that more of the blades surface is sprayed in the sterilizer resulting in a better clean.

4.7 PLC Control

The main control for the system was directed through the PLC. The PLC controlled most of the system's I/O (with the notable exception of the cameras) as well as the timing for the process. It also served to coordinate the data flow between the robot and the PC.

The PLC used was a Rockwell (Allen Bradley) CompactLogix system which was programmed using RSLogix 5000. There were no significant changes required for the PLC program during the commissioning stage of the project.
Other control items required included an SEW servo drive and motor to control the carcase stabilisation conveyor.

4.8 Safety Equipment

In order to ensure the safety of the system, a number of safety components have been utilised. Two safety relays are used which isolate automatic robot movement and the hydraulic power pack. Connected to these relays are a number of safety devices which ensure the integrity of the robot cell. The system will not operate unless each safety device is clear and the safety system has been reset.
There are two entrances into the robot cell. The first entrance is controlled by a gate and a fortress lock system. On the HMI cabinet, a fortress lock is mounted which houses a key. The key must be in this lock and locked for the system's safety to reset. In order to open up the gate, the key must be unlocked from the fortress lock and used to unlock the gate lock. Both these locks are captive meaning that the system can never be reset while the gate is open.

The second entrance to the cell is controlled by a safety mat. This mat triggers when a certain amount of weight has been applied to it (e.g. a person standing on it). Once triggered, the safety for the cell will be triggered and will require resetting to continue operation.
The system also possesses two E-stops – one on the HMI cabinet and one on the actual robot pendant. Depression of either of these will cause the system to immediately shut down. The safety system will not be able to be reset until the E-stop has been popped out.
Finally, the cell is isolated using safety guarding. The safety guarding is made with stainless steel posts and 6mm clear scratch resistant polycarbonate sheets. The safety guarding is designed to prevent personnel from coming in contact with the robot.

Figure 25 – Cell Enclosed by guarding

As an additional safety measure, it was requested that a lockable isolator switch for the robot be installed. When this isolator is switched off, the robot is unable to be moved; automatically or manually.

Figure 2 - HMI Cabinet with Robot Isolator, E-Stop and Fortress Lock

5 Success in Achieving Objectives

5.1 Success Rate

The system is currently in full production on-site at Swift's Dinmore plant. The most recent performance statistics place the success rate of the system at 97.19%. This has increased from the 94% which was achieved in September 2009. This rise in success rate can be attributed to a number of the variations outlined in section 4, as well as the tuning and modification of the vision processing application.

Figure 27 shows a breakdown for the causes of the unsuccessful cuts encountered. An unsuccessful cut is one where the robot has either:

- not gone in to perform the cut;
- gone in to perform the cut but missed the hock; or
- gone in to perform the cut but cut too low, thus requiring an operator to re-perform the cut.

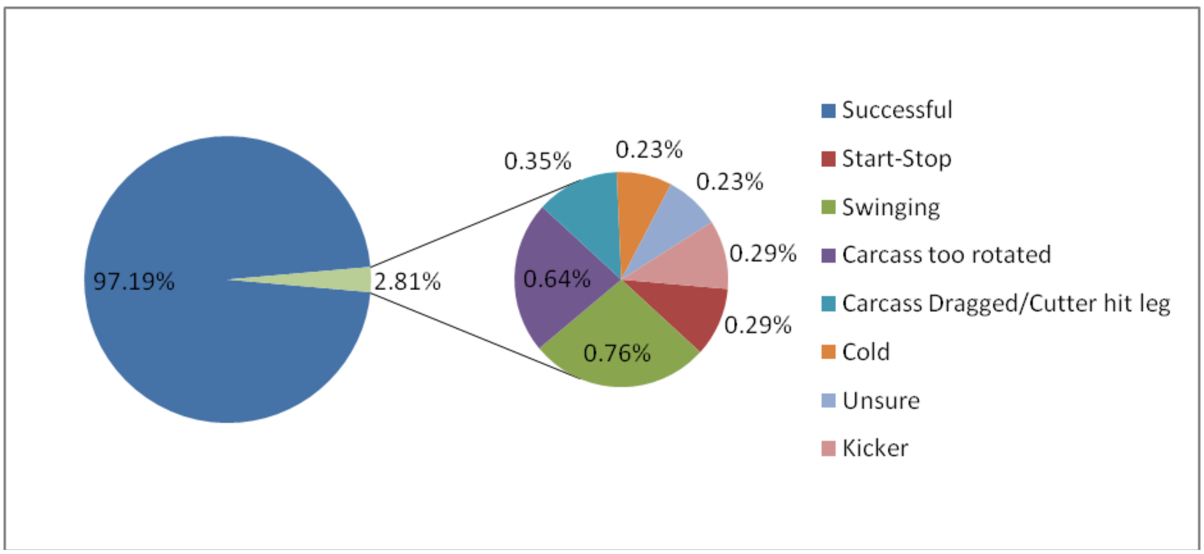

Figure 3 - Breakdown of Unsuccessful Cuts

5.1.1 Start-Stop

When the chain is stopped then restarted, this can induce swinging, especially as the chain actually runs backwards for a small amount of time before stopping. It may also cause the carcase to start rolling about its hip bone as the chain is stopped.

5.1.2 Swinging

Carcases may swing due to a number of reasons:

- rocking about their hip or ribs on the stabilisation conveyor;

- carcases dragged excessively between the two sets of stimulation rails (which are quite narrow) causing them to swing hard into the cell after the rails;
- not enough time for either case to stabilise before the first image is taken.

Figure 4 - Carcase Getting Dragged on Narrow Infeed to Cell

5.1.3 Carcase Too Rotated

This particularly refers to carcases being rotated too far towards the robot. In this situation the robot is unable to reach and make the cut without risking collision with itself or the fencing. This is generally an issue only with second cut.

Figure 5 - Over-rotated Carcase

5.1.4 Carcase Dragged/Cutter hit leg

Sometimes, due to carcase swinging, the cutters go too far back and cut a little into back hock when processing the front hock. This causes the jaws to catch the back hock and drag the body as the robot moves away from the cut. This is also sometimes caused by the cutters not cutting cleanly through the hide. Also, on rare occasions the cutter or clamp assembly knock the leg as it's going in to do a cut which cause it to miss.

5.1.5 Cold

Cold hocks affect visioning process as there is minimal data to work with. When cold hocks are encountered, the system relies solely on the stereographic image to locate a cut point.

5.1.6 Kicker

Sometimes due to nervous activity a carcase will 'kick' when a cut is performed. This generally results in excessive swinging causing the next cut to be unsuccessful.

5.2 Cycle Time

The cycle of the robot can be seen from the video that accompanies this report. The average over the five carcases in this video is 17 seconds, however it can be seen that the robot waits for approximately 2 seconds before each hock cut is made indicating that the system could run at a higher cycle time of 13 – 14 seconds. The system therefore achieves the desired rate of 240 head/hr.

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

The system has shown it is able to operate under the continuous, high line speeds encountered at Swift, which is seen as being one of the most challenging operating environments that can be expected. As a result, the system's ability to be easily integrated into other processors' chains can be expected. It is thus felt that the system has the potential to have a significant impact on the red meat industry within Australia.

6.1 Estimated Cost Benefits

The cost benefit will be in terms of labour reduction, suppression of OH&S claims related with the task, operational improvements, and Yield gains achievable through better tendon recovery.

The Robotic Beef Hock Cutter will replace two skilled operators per working shift.

The potential cost/benefit for a commercially available Beef Hock Cutting System indicates the following based upon all known process data, historical data from previous installations and taking into consideration all known or conservatively estimated Cost, Losses Gains & Savings.

Key Assumptions:

- 2 shift per day plant +800 head/day
- Installed System Cost = $ 400K
- Labour Savings per year = $ 128K
- Nett yield gain per year = $ 50K
- OH&S Savings per year = $ 15K

POTENTIAL COST BENEFIT – COMMERCIAL SYSTEM		
Gross Benefit Per Head	*Over Year 1*	$0.36
Nett Benefit Per Head	*Over 10 Years*	$0.16
Net Present Value	*NPV*	$808,513
Profitability Index	*PI*	3.02
Payback time in years		**2.6**
Internal Rate of Return	*ROPC or IRR*	41.96%

Further evaluation of the Hock Cutter System installed at Swift Dinmore will be conducted in 2010 to determine a more accurate Cost Benefit Analysis.
This CBA evaluation will be conducted by a 3rd Party and will be supported and funded by MAR and MLA.
Additionally MAR is currently investigating further enhancements to the Beef Hock Cutter by introducing a 2nd process task.
A second task will remove additional labour with similar OH&S and yield gains achievable.
The most suitable second task yet to be determined may include hide opening cut, horn removal or ear tag removal among other ideas being investigated.
Inclusion of a second task is imperative to ensure the viability of this technology for plants operating with single shift and lower heads per day.

7 Conclusions and Recommendations

The key objective for the project was thus to develop and trial an automated beef hock cutting system and prove its ability to perform in production. This was to be achieved through the integration of three key elements: sensing technology, robotics and a cutting mechanism.

Such a system was expected to provide benefits related to:

- reduction OH&S-related insurance costs and claims;
- labour reduction;
- removal of training requirements;
- increased productivity;
- minimisation of waste; and
- higher levels of hygiene.

The system was also expected to operate under a number of strict and challenging conditions. It was required to operate in an autonomous manner, with an operator only required to start or stop the system or change the cut specification if required. It would have to operate effectively for continuous line speeds up to 240 head per hour and show the ability to process all sizes and breeds of beef encountered at the facility. It was also expected that the system be able to operate under all temperatures experienced at the plant and be able to withstand the demanding conditions endured during chemical washdown. Finally, there were strict requirements placed on the cell's footprint as well as hygiene.

The system design was based off work previously conducted by FSA and, while a number of challenges arose in the commissioning phase of the project, the system stayed true to its basic initial design principles.

One of the key challenges faced was that of carcase stabilisation and presentation. In order to maximise the chance of creating a reliable system, it is required that the carcases are presented as consistently as possible and that they remain stable during their transition through the system's cell. The higher the level of variation which occurs, the higher the chance of either the visioning process failing or the robot missing the hock. Addressing this issue required a number of modifications to the initial carcase stabilisation plan as well as a number of changes to the location of the cameras within the cell. The latter of these also brought about significant changes to the vision program due to re-tuning of tools and the requirements of new mathematics for cut position calculations. Designing a method of completely eliminating carcase swinging would provide improvements to the success rate of the system. However, a feasible solution to this issue is yet to be determined.

Other issues encountered included: the positioning of the wash tank; lighting; the requirement for a faster and more effective robot recovery routine; missed cuts; and cut orientation.

Despite the challenges faced, the system is now running in full production with a success rate of over 97%. The system has shown no issues with cycle time, showing its ability to operate under even the fastest chain speeds encountered. The training of electricians, fitters and operators has also been conducted. This project has been quite successful in proving the ability to automate the task of beef hock cutting, especially in an environment as challenging as that presented at Swift's Dinmore plant.

Some recommendations for future implementations include:

- finding a more effective means to prevent carcase swinging and create more consistent carcase presentation (this will be plant-specific);
- ensure that the robot is given as much space as possible to work in;
- ensure the system is placed as close as possible to the knocking box;
- finding a more robust robot covering solution; and

- making the sterilisation process more effective through the use of more rows of nozzles.