final report

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Robotic Ovine Cutter – ROC 400

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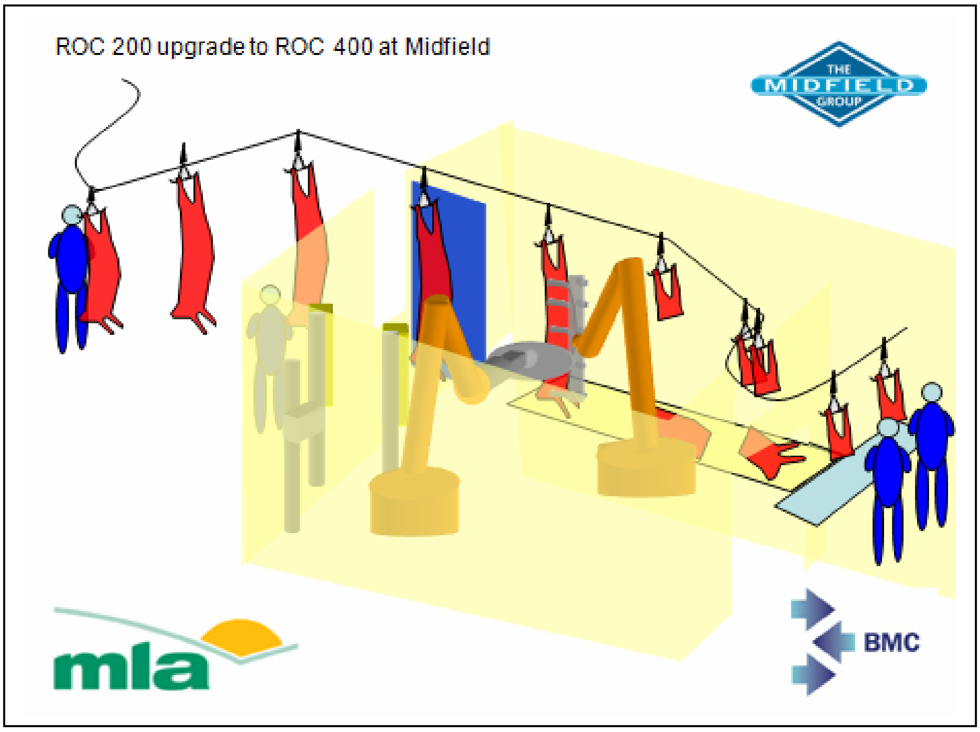
Abstract

Robotic cutting of lamb was first achieved at Midfield in 2005 using a single robot operating at 200 carcasses an hour. The system used a multi-finger gripper and a hook attachment mechanism to grasp and manipulate, using a standard industrial robot, a whole lamb carcass against a cutting knife blade making two cuts: the shoulder and the leg cuts. The operation of the robot was guided by a vision system analysing the side profile of the carcass and the robot producing cuts anatomically adjusted for optimum position to better accuracy and consistency than achievable manually with a bandsaw. In 2009, MLA and Midfield Meat undertook a collaborative project to provide a solution that performs the same cuts at improved accuracy and at 400 carcasses per hour. With input from partners involved with the first installation, BMC, E+V and Freund, Midfield reached the upgrade using two robots, one grasping and positioning each carcass after determination of cut positions by the vision system and a second robot performing the cuts. The project achieved improved accuracies as expected at the target speed in the summer of 2010. The system is in daily use cutting Ovine carcasses (including lamb and mutton) every day.

Executive summary

Manual break up of carcasses anatomically has been a topic for robotic application for many years and Midfield has been among the first to achieve a working solution for practical use in the meat sector. The first solution was reached in conjunction with BMC, E+V and Freund in 2005 as project internal to Midfield. The system has been operated daily by Midfield since its installation and under this MLA project an upgrade, executed in two stages by the total team, has meet the objectives of improved speed and better accuracy.

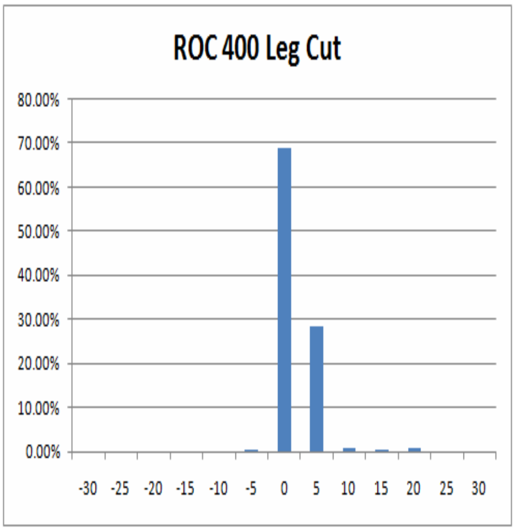
The system as shown in the figure below, now uses two robots, one for grasping and positioning the carcass and another to perform the cuts using a vision system arrangement that locates each cut anatomically. The cuts performed are on the Ovine range of carcasses including lamb in the range of about 12 Kg through to 30Kg or heavier and mutton that could exceeds 45Kg in weight. The cuts specified for the robots are the 4^{th}-5^{th} rib shoulder cut and the leg cut. The processing cycle is up to 400 carcasses per hour.



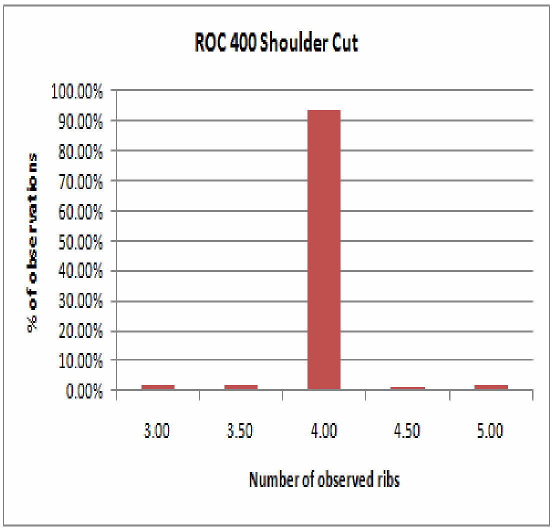
Carcasses arriving on the left of the figure above undergo manual trimming and inspection at two stations, one station before an incline conveyor, which raises the carcasses to a high level, and a second station after the incline before entry to the robot cell. The second station allows each carcass to be inspected and trimmed at the shoulder and with the orientation of the carcass controlled; the carcass enters the robot cell after this station. The first station inside the robot cell is the vision station where camera and lighting system using a blue background acquires the image from the carcass side to perform image analysis and with the use of appropriate equations the cut positions are determined. This information is used at a next station after the vision camera for a robot to grasp the carcass using a special design gripper and position it correctly for a second robot to perform the two cuts. A Freund 950 mm knife blade with a standard motor drive and gear assembly is used to perform the cutting at the shoulder and also at the leg. The shoulder primal, and the middle primal are placed on a conveyor for transfer out of the robot cell and the legs hanging on the hook travel down a decline section out of the cell to manual leg de-boning stations as may be seen to the right of the robot cell in the figure. The cell is fully enclosed by wall partitioning and the only entrance is through a chest high gate at the second trim station. This gate is interlock wired to the emergency stop circuit of the total system and prevents access through or over the gate when the system is running.

The system automatically adjusts the cuts to accommodate for carcass size and shape variation and at the same time the user has the option to adjust the position of each cut relative to the nominal position determined by the vision system for a given run. This allows for optimisation of yield in primal cuts as well as adapting to customer specifications. The system also adjusts the cur angle on the shoulder cut where this is needed, especially in the case of Mutton.

The system performs to an accuracy reported by independent evaluation (refer to separate report available for the MLA) as shown in the charts below for leg and shoulder cuts respectively.



Over 95% of leg cuts within ± 5 mm



Over 90% of cuts at 4th rib

The performance of the cutting has been assessed for benefit for an average size processing plant in Australia, where the return on investment is estimated at less than 12 months. The benefits are from improvements in yield compared to a manual operation using a bandsaw, improved safety, better shelf life relating to reduced bone dust and labour savings. Machinery Automation and Robotics (MAR) in Australia and New Zealand have the commercial agreement for supply to processors at a competitive price. For further information and arrangements for supply please contact MAR.

Contents

Figures

Tables

1.0 Background

Figure 1.1 shows the arrangements of the system at Midfield prior the changes under the ROC 400 project.

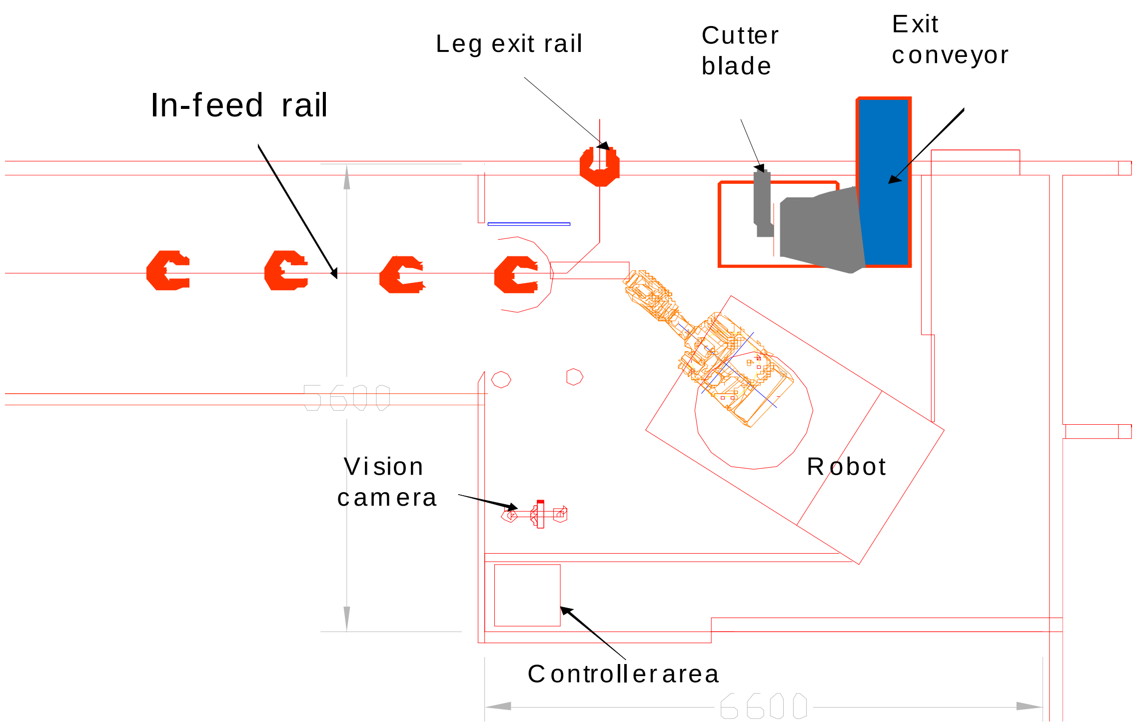


Figure 1.1: System components and layout prior to start of ROC 400 project

The main elements and the operation of the system were:

a) An in-feed rail of indexing design delivered fully trimmed and prepared whole carcasses hanging by both legs on standard plastic hooks. Carcasses were indexed at a rate of 6 seconds with the open belly travelling in the direction of motion towards the robot (left to right in Figure 1.1.

b) A vision system comprising E+V technology took an image of each carcass and based on software implementation specific to the system, cut positions were determined using external features and specific geometric and feature based models.

c) A six axis robot carrying a gripper module developed by BMC and Midfield. The gripper has features that allow the carcass, after imaging, to be held by the hook and by attachment to the carcass for it to be carried with minimum movement to a vertically mounted cutter. The robot is integrated with the vision system and performs the cutting at the positions determined by the image analysis software.

d) The cutter tool is a standard Freund cutter that was mounted vertically in an arrangement that allows the carcass, held in a horizontal attitude in the gripper, to be driven against the blade to achieve through cuts.

e) The cut shoulder and middle were released on an exit conveyor immediately after the leg cut was performed and the leg primal still held by robot gripper attachment to the leg and the plastic hook was re-hung on an exit rail that carries the leg primal in a vertical position out of the robot cell under the force of gravity.

f) Adjustments to the cut position has been an automatic feature in the vision system with the added operator interface on the vision system computer screen for any small adjustments to the cutting position relative to the automatically determined cut from the imaging software. Cutting was performed at 200 carcasses per hour on average.

2.0 Project objectives

The objectives of ROC 400 project have been to scale up the original system developed by Midfield and BMC to a higher throughput system and achieve improved accuracy.

The robotic cutting system prior to ROC 400 project was shown to perform to double the accuracy performance results compared with an operator on a band saw. The cut program has been set to make the shoulder cut between the 4th and 5th ribs and the leg cut close to the vertebra gap above the Last Lumbar Vertebra (LLV) avoiding as best as possible pin bone in the short loin.

2.1 Cutting requirements

Figure 2.1 shows the schematic of the position requirement for cutting.

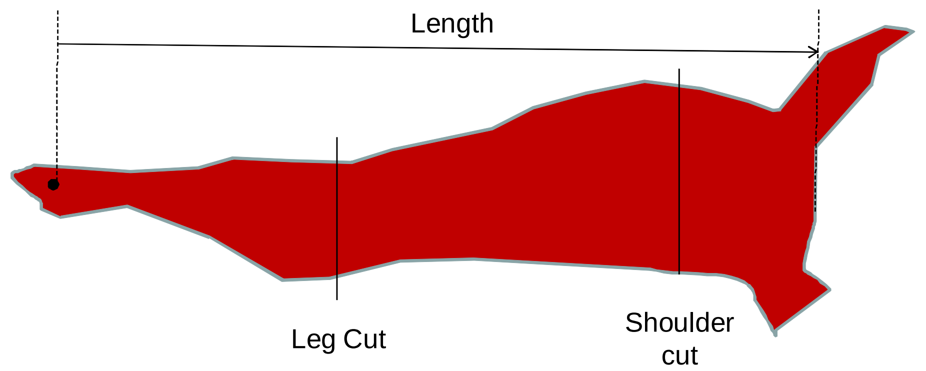


Figure 2.1: Required cuts

The ROC 400 upgraded system was to achieve cuts as shown in Figure 2.1 separating the Shoulder, the Middle and the Leg primal cuts. The accuracy of the cuts to be at least as good, if not better than, what has been achieved by the system at 200 heads per hour.

2.2 Product range

The product range and target accuracies for ROC at 400 carcasses per hour were set as follows:

Carcass range: 1100 mm – 1500 mm in length
Length is as defined in Figure 2.1 from the hook entry point in the legs to the bottom of the breast.

Carcass weight: 12Kg-40Kg.

2.3 Leg Cut

Leg cut accuracy: deviation from nominal cut as a straight cut through the vertebra gap above LLV with a deviation not exceeding ±7 mm for 80% of conforming carcasses and ±10 mm for the remainder.

Adjustment accuracy for repositioning the cut: ±2 mm relative to the position determined by the imaging system.

2.4 Shoulder Cut

Shoulder cut accuracy: to be made between 4th and 5th ribs with deviation from nominal cut as a straight cut through the gab as an orthogonal cut not exceeding ±7 mm for 80% of conforming carcasses and ±10 mm for the remainder.

Adjustment accuracy for repositioning the cut: ±2 mm relative to the position determined by the imaging system.

The angle of the cut may vary, given that the line between the 4th and 5th ribs is not orthogonal to the vertical with the carcass hanging from the hook. The angle for a range of lambs observed and analysed during recent cutting trials at Midfield is found to be about 3.1 degree on average and 6.5 for mutton. As a new objective in the project the system compensates for this natural angle on a carcass by carcass basis, allowing the line of the cut to fall more closely between the 4th-5th rib gap (See Figure 2.2).

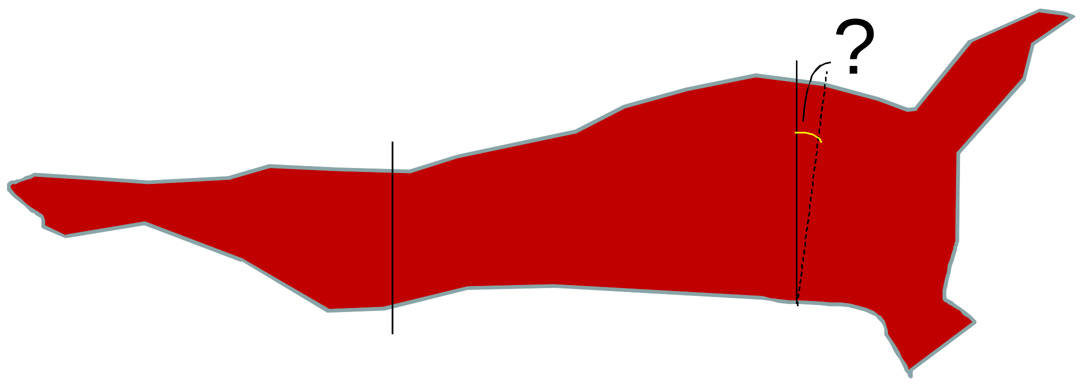


Figure 2.2: Shoulder cut angle

Note that in the ROC 200 system the lack of compensation capability for this angle resulted in the cutting of the 5th rib at the tip of the rib leaving a part of the 5th rib attached to the shoulder, where it is normally to be attached to the middle. The proposed compensation for angle allows this to be improved.

3.0 Methodology

One of the important challenges in a project of this kind is the management of implementation in such a manner that has minimum impact on the production commitment to daily work. Interference is inevitable; however, the challenge here was even greater as the ROC system upgrade needed to be in stages that allow after each change for the system to be used for production as this was a key factor in the business. Midfield planning and allocation of resource needed to include the development effort as well as the effort to produce whilst changes were being made to a key piece of plant equipment. This challenge was met with considerable professionalism and diligence by the engineering team and those operating the Midfield boning room during a three stage upgrade.

3.1 Specification and site implementation

The specification of the changes to achieve the cutting speed of 400 carcasses per hour, without compromising accuracy and cutting, needed to be supported by specific implementation of the two robot system to be used for testing initially and later for production.

In particular the changes to achieve the speed were to be reached by introducing a second robot to make the cuts. The stages of the project were thus as follows:

a) Site changes and introduction of new services that allow the installation of the second robot whilst keeping much of the original system components the same. The main targets here was to avoid movements of the robot replacing the leg back on the rail as the cutting by the second robot would be performed with the carcass held by the gripper and the second robot moving the blade to perform the cuts. This replaced the action to push the carcass against a fixed blade.

b) Addition of a more flexible gripper to widen the range of carcases and improve the way in which the carcass was held for accurate positioning of blades at the desired cut position without the possibility of the robot fingers being in the way, which was a constraint of the old gripper.

c) Integration of the final solution with two robots cutting 400 carcasses per hour where the line positioning allows bigger carcasses, especially in the mutton range to enter the system. This was to be achieved by raising the in-feed by 850 mm whilst allowing for the carcass trim functions and the QA inspection processes to be possible with compatibility to quality monitoring standards. Special features were included to allow post and pre trim inspection checks to be performed without any significant changes to the practices that are formally required according to Australian standards. Integration was to include several important aspects dealing with leg exit and transfer of the shoulder and middle cut primal pieces to the next stages of the line, ensuring proper flow and interfacing with subsequent break up and de-boning tasks.

Figure 3.1 shows the schematics of the installation for ROC 400, which was achieved in September 2010.

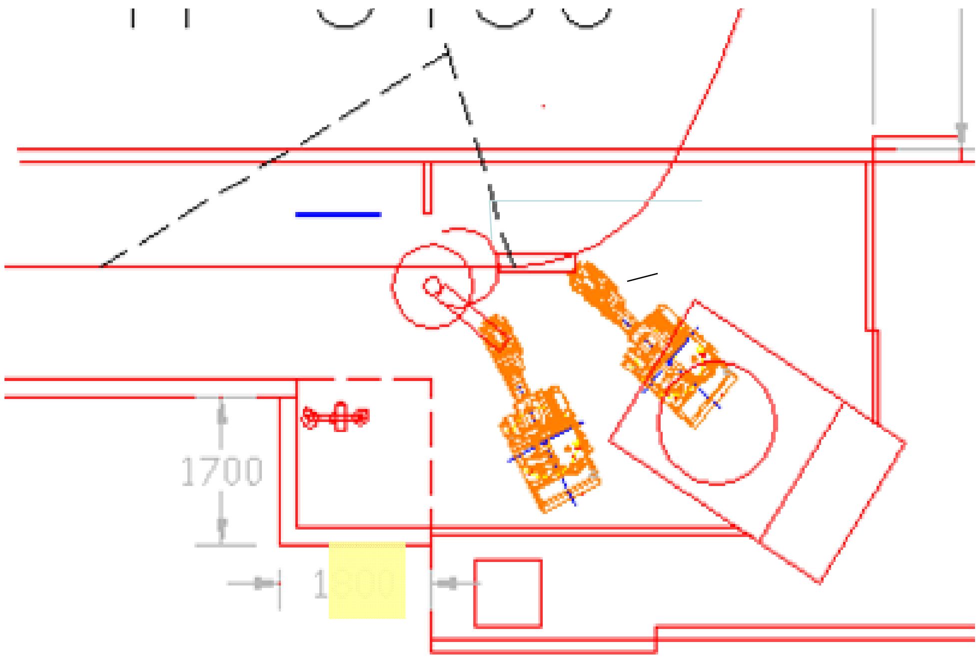


Figure 3.1: ROC 400 site changes and installation of second robot

3.2 Work completed

The work completed includes the following:

i) Changes to the room and re-location of services

ii) Re-positioning of the safety guards and electrical integration of the interlocks

iii) Positioning and commissioning of the vision system in the new location

iv) Positioning and commissioning of the second robot

v) Building an addition of a new gripper

vi) Introduction of incline section and process for post and pre trim inspection of carcass trimming prior to entry to the robot.

vii) Introduction of an automatic wash system

viii) Introduction of rail and conveying for cut primal poices to be delivered to the next stages of production.

ix) Full programming and de-bugging to allow smooth day to day operation.

Figure 3.2 shows the status of the final system, which has been in use after each stage of up grade on a daily basis and after its concluding integration since September 2011.

Figure 3.2 Integrated systems are presented in sections: starting with the incline section and manual trim. The first station after trim is the E+V vision station (bottom right - vision screen) followed by the two robots one holding gripper and the other the Freund cutting tool (left- picture taken during development set up). After cutting the legs travel on a decline rail to boning stations and the shoulder and the barrel exit on flighted conveyors to the next stations in the line (top right).

One of the main advantages of the system is its simplicity in set up and configuration with minimum hard automation (see Figure 3.3). The programmability of the system allows extension dealing with other carcass types such as calves and the entire Ovine range.

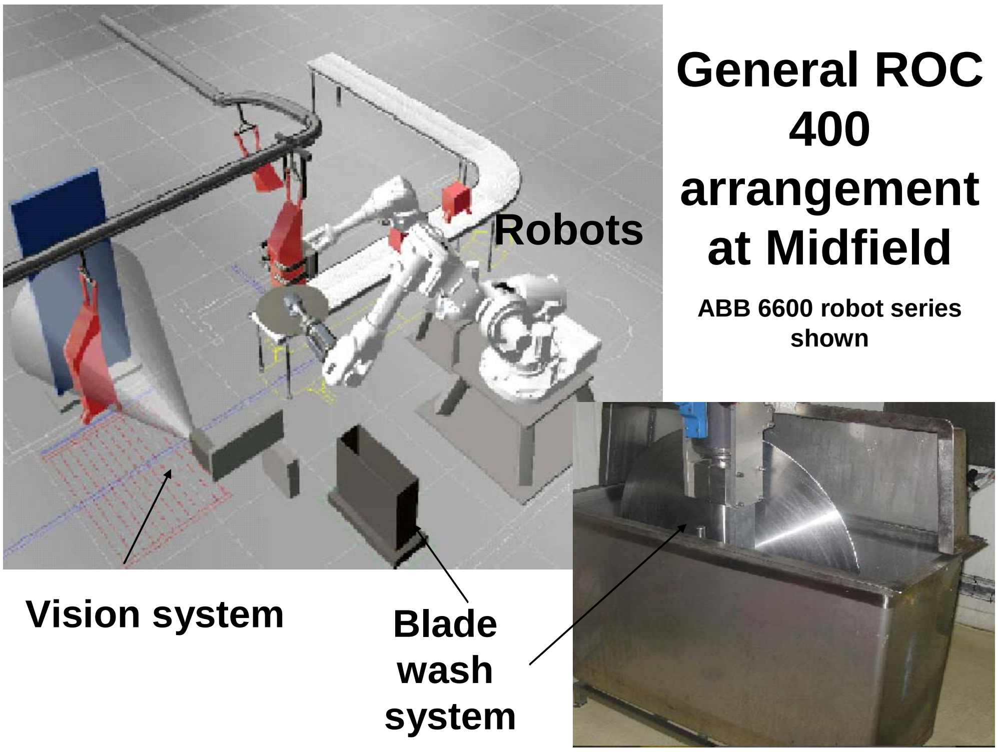


Figure 3.3 ROC 400 arrangement with ABB robots. System is now available from MAR (Machinery Automation and Robotics) in Australia and New Zealand.

4.0 Results and discussions

The results of the project are presented in this section in three parts making reference to current practices and demonstrating the advancement beyond state-of-the-art in process automation for industry. The specific areas are:

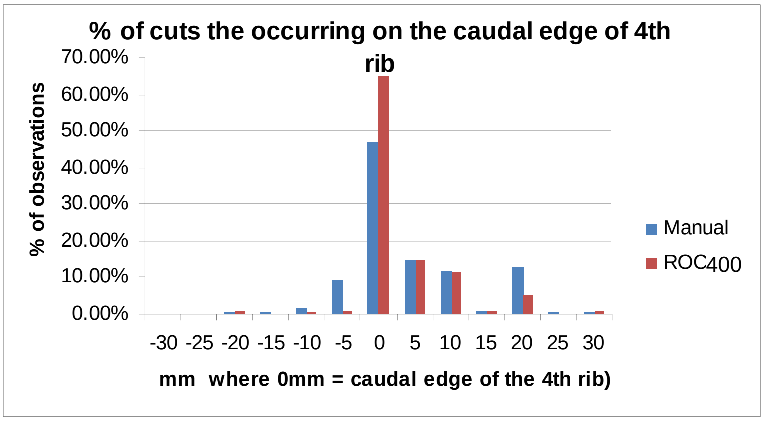
- Accuracy over current manual processes in a cost effective manner
- Increased cutting speed according target rate of 400/hour against the maximum rate achieved by the original system at 200 heads/hour
- Maintaining quality of cuts, whilst improving the Operational Health & Safety in the work environment.

4.1 Accuracy

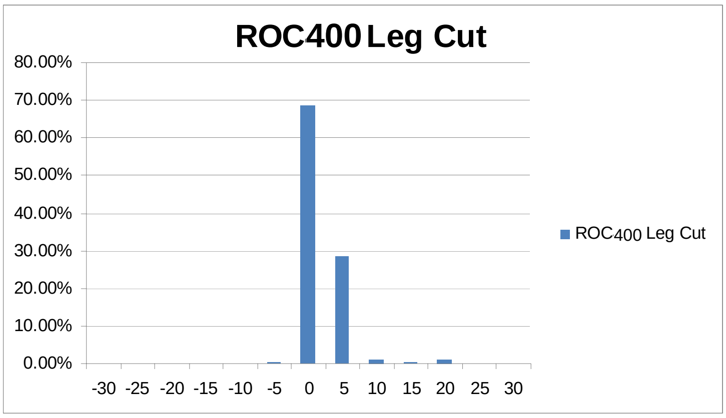
The ROC 400 system uses a vision system with evolved cut equations from that of the previous system using a near neural network approach. The method correlates features in a ‘learning’ process that uses correct and inferred positions of cuts to self-tune the set of parameters with appropriate weightings on key carcass features that increase cut position calculation accuracy.

Figure 4.1 presents the independent assessment for cut accuracy in manual and ROC 400 cutting of the leg and the shoulder cuts.

The important observation is that the system performs with greater accuracy that can be observed from manual processes by a significant degree and that the cut positions may be adjusted for a given run with a simple change on a menu that allows offsets to be entered where this will give better yield on higher value primal cuts (see Figure 4.2).



Shoulder cut assessment
(see Greenleaf report available from MLA)



Shoulder cut assessment
(see Greenleaf report available from MLA)

Figure 4.1 Cut accuracy

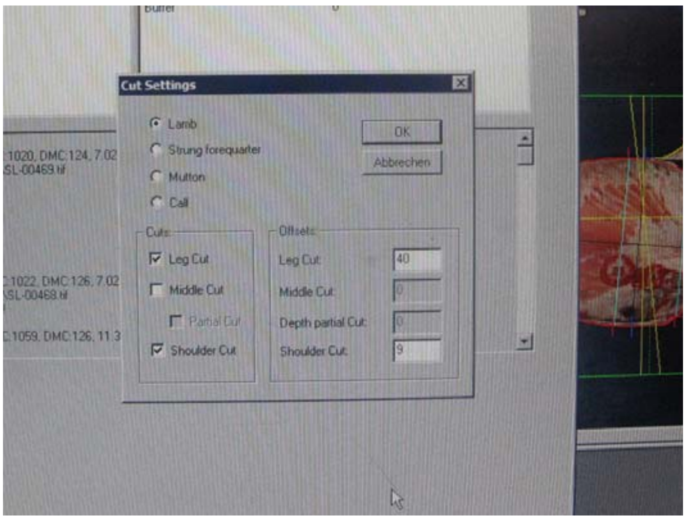


Figure 4.2 Adjusting cut positions using vision menu

The optimisation of the cuts on a batch to batch basis, for different customer specifications is an important industry requirement and this was implemented using the vision menu shown. Note that the accuracy of the system is not only related to the imaging or sensing capability to determine the cut positions referenced anatomically, but also the capability to physically handle and position carcasses relative to the cutting system. The data assessed an presented here is the total system performance and not just the vision system, which in effect is performing to greater accuracy to yield such results.

4.2 Speed

Table 4.1 presents the cut assessment for based on an evaluation of movements and cycle time of each action.

ROC 400 Cut cycle and rate assessment		
item	Seconds	Step
1	1.46	Move to grasp carcass
2	0.30	Carcass in position for cutting
3	1.36	Grip carcass and move to cut position
4	4.98	Cutting cycle
5	0.80	Primal cut release
	8.90	**Total**
	404	**Estimated rate per hour**

Table 4.1: Cycle time assessment

It is important to note that the overall throughput is a function of the in-feed rate and the rate at which the primal pieces may be taken away form the system.

4.3 Quality

The quality of the cut may be measures with respect to the capability to meet the expected consistency of the cut as determined by accuracy, but also by the reduction of bone and meat dust compared with manual cutting.

Figure 4.3 shows the cut faces for the shoulder primal pieces taken from the primal cuts produced by ROC 400 system. The Leg cut is the same.

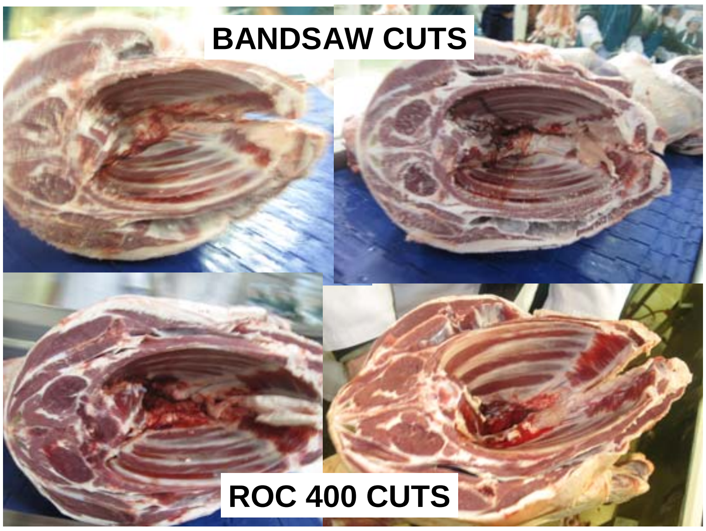


Figure 4.3 Cut quality comparison ROC 400 vs Bandsaw

5.0 Related issues

Several other aspects of the project are considered worthy of mention.

5.1 Training

It was considered important that Midfield develop a training program to increase the support for technologies form within the company than relying on outside organisations. This is particularly important to the day to day running of the plant as the nearest service resource is at least 4 hours away.

Staff with electrical, mechanical and software skills were identified and engaged with the project during implementation, shadowing robot programmers and executing the installation and assisting the commissioning where applicable including the vision system.

Those who were to become responsible for the day to day were put through training on all aspects of the system from operation to repair.

The engineering team at Midfield were directly involved with the implementation of the system especially the gripper subsystem, the handling and conveying and also the safety system. In particular the implementation of the operator interface was conceived by Midfield ensuring that all at the plant are fully aware of the MMI unit which is of a simple design and robust for the purpose intended (see Figure 5.1).

Figure 5.1 Operator panel for ROC 400

5.2 Economic benefit

Of particular relevance is the benefit of such a project to other processors in Australia. An assessment report from Greenleaf is available and the main benefits from such a system calculated summarised in given in Figure 5.2.

Cut accuracy, Sawdust reduction, shelf life, throughput consistency, OH & S and efficiency are considered and reported.

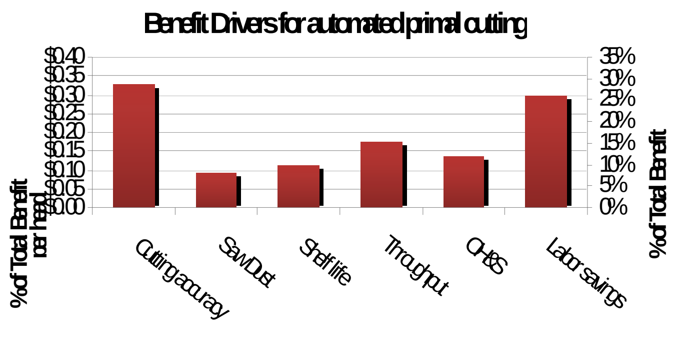


Figure 5.2 Benefits from ROC system projected for an average plant processing up to 450 heads per hour and performing 2-4 cut by a ROC system.

6.0 Concluding remarks and acknowledgements

The ROC 400 project has met its objectives in full delivering against the objectives as defined in the MLA-Midfield contract P.PSH.0510.

The system was an upgrade of a solution developed by Midfield and BMC (UK) and the 3 stages of upgrade were followed by several weeks of production run to trouble shoot the key issues preventing reliable operation.

The final stage was concluded in September and except for a few small matters of component failure in particular switches, early mechanical failures in the gripper and specific software bugs, the system has now reached stability and is ready for commercialisation, which is a phase being followed under the ROC 450 project.

Special thanks go to Midfield Meat, BMC, E+V and Freund making the MLA project reach its conclusion and in particular the engineering team at Midfield. Special recognition is due of the efforts of Shane Wittmann, Pudd Murphy, Chris Alsop, Travis Hayland, Simon Schrama, Paul Ryan, Adam Kelson Matt Fisher, Paul McWalter and the whole maintenance team. The efforts of Craig Ashmore and Ralf Rothe are much appreciated.

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