FINAL REPORT FIRST FEASIBILITY OF SHOULDER DE-BONING

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1.0 EXECUTIVE SUMMARY

The meat industry has a major requirement to automate its processes of slaughtering and meat preparation including primal cutting, sub-primal breakup and de-boning.

This project was proposed in 2016 to carry out a feasibility of de-boning lamb shoulder primal pieces, following discussions and the declared need by several Australian meat processors. In particular, the separation of the rib cage was to be evaluated and a solution for implementation as a prototype intended. The original approach considered similar steps to that applied by BMC (Koorosh Khodabandehloo) for the ATTEC Shoulder cutting to produce bone-in square cut pieces.

The specific tasks included the assessment of shoulder primal variability in relation to de-boning as intended for automation. Cutting trials and generation of a blueprint of the solution has been intended and reached through the milestones of the project, which also included practical trials. This report provides results with an estimation of the cost for a twin robot solution that minimises the use of dedicated mechanisms and automation, whilst accommodation variability.

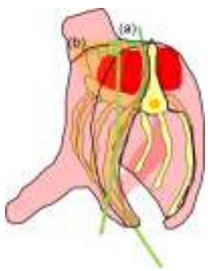
The main variability in dimensions influencing the deboning steps include:

- the overall width which varies by 40 mm about the main axis of the spine, with minimum width being 210 mm and maximum 290 mm,
- the overall length ranging 135 mm to 230 mm,
- Effective height excluding neck section ranging 265 mm to 335.

The method of deboning by hand has two options with the neck removed by band-saw before deboning or the neck left on.

The process steps to separate the rib cage involves the following actions:

- Separation of shoulder muscle from the spine featherbone by performing two knife incisions one on each side of the featherbone along the back of the shoulder.
- Separation of the foreleg and shoulder muscle from one side of the rib cage and then the other side of the rib cage (see image).
- The foreleg-shoulder pieces (the banjo) are then de-boned further by removing the leg bone and the shoulder blade, leaving the bone in shank intact and remaining attached.



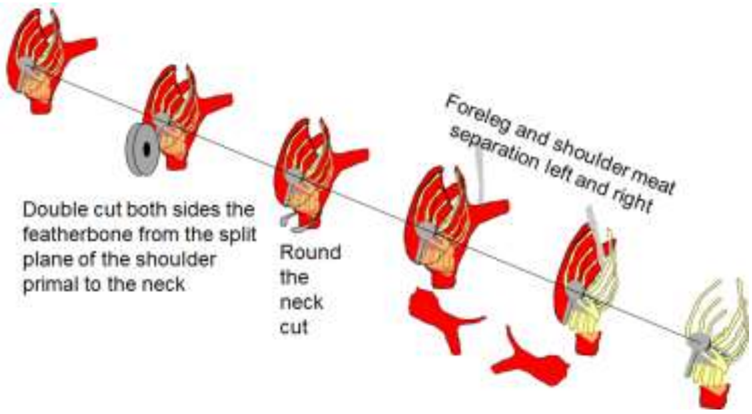
The approach to using automation would remove 30%-40% of the whole manual processing time, when focusing on the separation of the shoulder rib cage.

Trials and observations of the processes have been conducted and two practical options have documented that represent the manual process.

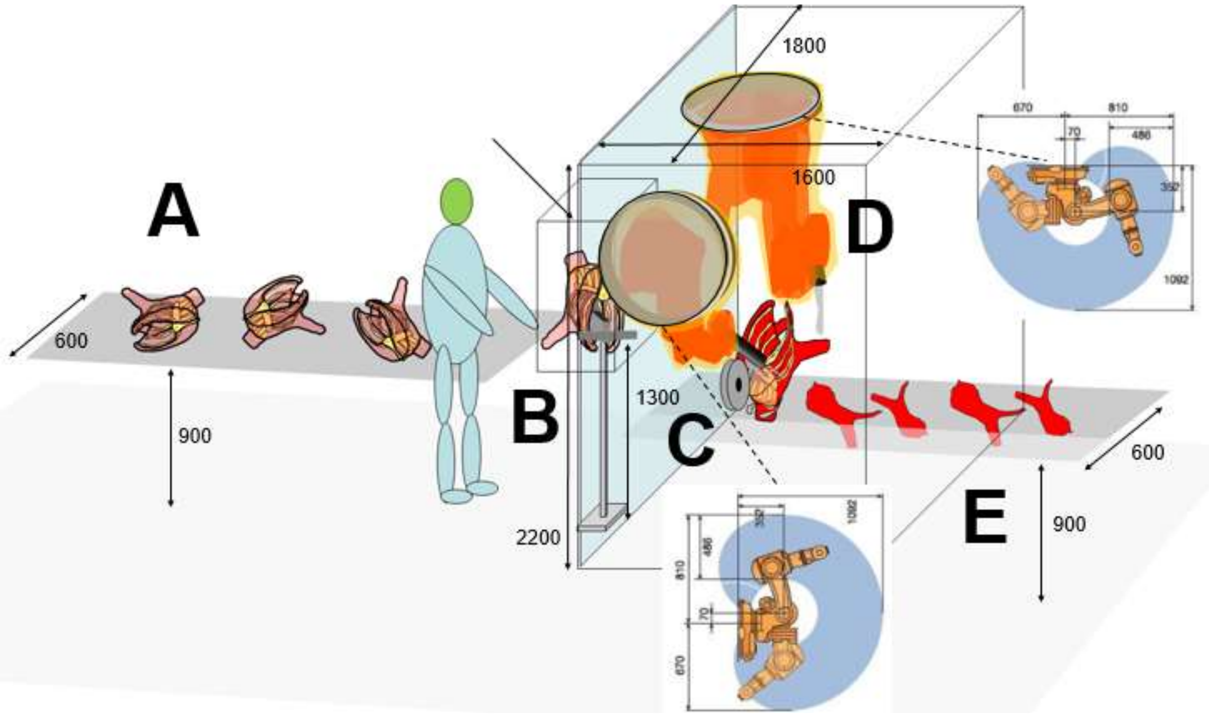
a) Separation of meat in the whole shoulder, neck and leg or the “banjo” as one piece, from the shoulder carcass, leaving behind the shoulder carcass, with the neck attached,
b) Separation of the banjo from the shoulder leaving behind the neck and shoulder muscles for the production of shoulder cutlets.

Assessments of the cutting schemes with cutting tool possibilities has been made and a robotic approach is identified as a solution for further examination.

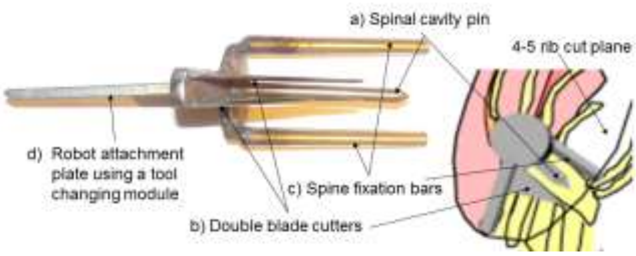
The arrangements for a robotic solution has been sketched forming the bases for detailed evaluation and development which is to be supported by further trials and generation of a blueprint drawing of the solution.



The Figure provides the overview of the automated steps and the blueprint of the proposed Twin Robot Cell for lamb shoulder de-boning. A fixation solution is required for handling.



The key to the feasibility supporting the solution is a handling fixture, which has been tested by the project (see actual model in image opposite), and force controlled rib profile robot using a knife with a standard off-the shelf 6-axis sensors available with an ABB robot, applying methodology from past research by Khodabandehloo et al. A full development proposal is put forward to the AMPC in response to the 2017 call for projects to reach a first prototype in 2018.



2.0 INTRODUCTION

The meat sector is targeted to have significant labour shortages as the demand for food increases in the next few decades. Automation capable of accommodating the required processing throughput in an efficient and cost effective manner will be a key factor in the sustainability of meat supply at the future volumes.

This project has been focused on the separation of the ribcage from a whole lamb shoulder primal in the task deboning, reducing the reliance on people's time on the production line saving equivalent of 2 units of labour in the overall task at 300 pieces per hour.

The purpose of the feasibility has been to evaluate the potential and establish the understanding that supports the realisation of practical automation for de-boning lamb shoulder primal, accommodation for the variability in shape and size, which has also required quantification. The range considered is from lamb carcasses in the range 15Kg-40Kg whole. The process of deboning has been examined in relation to other primal pieces including lamb leg (by Scott Technology) and beef forequarters (Khodabandehloo, et al).

The project had the objective to adopt a dedicated approach, based on the ATTEC range of machines, but this was not considered realistic, given the range of variability in shoulder primal pieces.

The alternative to defining the requirements and the method for separating automatically the shoulder rib carcass from the primal piece has been to use a robotic approach and the scheme for separation is based on similar techniques used by butchers, but structured for robotics. This is targeting the ribcage separation, which is difficult manual process (See Figure 2.1).

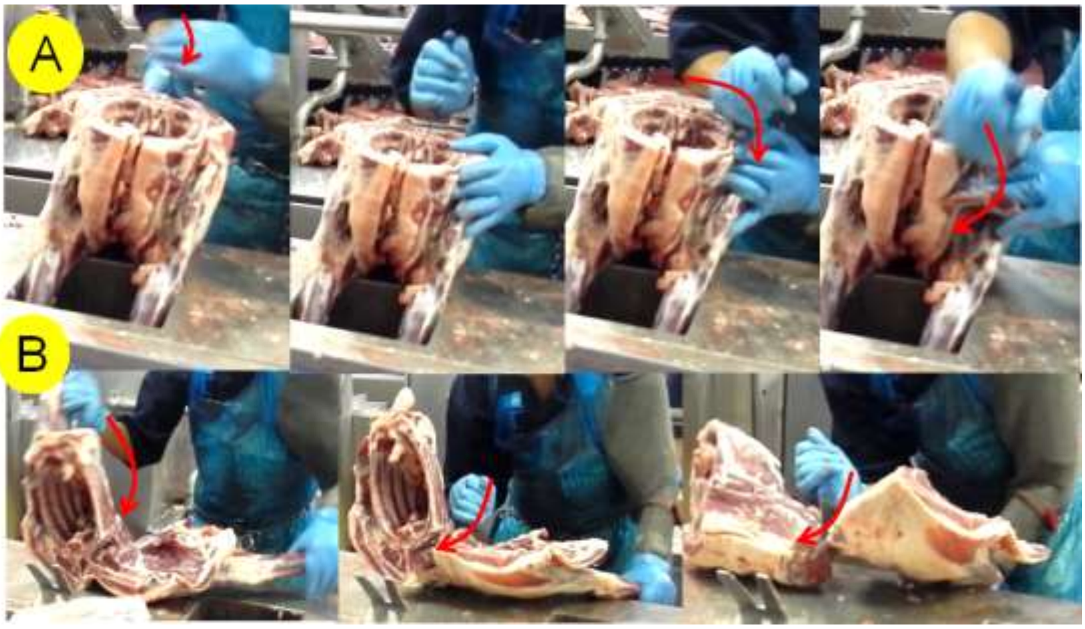


Figure 2.1: Pre-cutting of the eye muscles adjacent to the featherbones as in Figure 1 left, starts the process. Cuts along the 4th rib (A) are followed by cuts in (B)– separating the full shoulder muscle with the banjo as one piece.

Once the ribcage is separated, the de-boning of the foreleg would be manual following. Figure 2.1 presents the approach to process of the deboning being targeted by this feasibility.

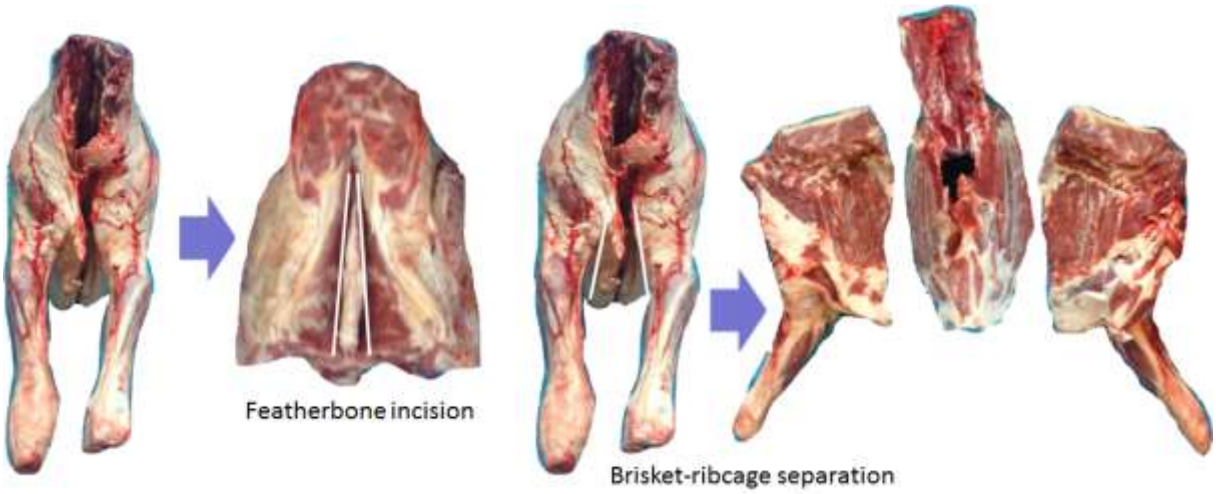


Figure 2.2: Target deboning task

The limitation in using standard automation and the approach to resolving such limitations are as follows:

- // A conventional machine may not be conceived for shoulder de-boning given the variability and the manipulation complexities in the process.
- // The range of variability requires adaptation of the cut path separating the ribcage without compromising yield, which cannot be achieved by shaped blade cutting tools, originally I intended at the first proposal stage.
- // A robotic approach, however, can generate practical results,
- // A simple low cost fixation solution for holding and handling shoulder primal pieces is necessary.
- // The approach for deboning using industrial robots, adapted for use in the meat processing environment, may be. A system solution, incorporating force sensing is considered the correct approach, which will also have spin-off relevance to other de-boning processed.

The remainder of this report provides the methodology and the results of the feasibility.

3.0 PROJECT OBJECTIVES

- // Assess the range of variability and user requirements.
- // Define tools and conduct trials.
- // Based on the outcome, produce a blueprint of the machine and estimate its cost.
- // Define follow up project and produce final report.

4.0 METHODOLOGY

The methodology of the work has been to quantify the range of variability in shoulder primal sizes that are likely to be de-boned by the industry, examine current practice and document the target process and based on practical experimentation and de-boning trials, define an automated approach for separation of the lamb shoulder ribcage form its whole primal.

The definition of the process the approach to the solution has been examined, based on the manual method for separation of shoulder primal, quantifying the size range, whilst identifying a feasible solution that may be implemented. Parallel considerations have included the ATTEC square cut shoulder machine, the Scott Technology shoulder break up solution using robotics and the Scott Technology robotic leg boning. The following have been considered:

- Method for separation and manipulation,
- Method for holding shoulder primal,
- Cutting tools and the approach to use for deboning,
- Integration and definition of overall process for automation.
- Machine design in concept,
- Trials to support design solutions for sub-elements,
- Definition of the solution leading to the blueprint of the system.

Practical workshop trials have been conducted in a systematic manner to reveal the method for de-boning a lamb shoulder primal using a standard robot including:

- Definition of a fixture for holding the shoulder primal, with the specific features that firmly maintain the skeletal structure of the shoulder primal ribcage in 3D space.
- Definition of a handling system that allows for lamb shoulder primal pieces to be manually loaded onto the fixture in a safe and an ergonomically friendly manner.
- Definition of a handling system that allows the primal pieces to be transferred to a guarded area and presented in a referenced position and orientation for robotic de-boning.
- Definition of a robotic process for separating the fore-leg and shoulder meat from the rib-cage leaving the ribcage carcass on the fixture, with the separated meat and foreleg falling under gravity on to a transfer conveyor. Placement of the ribcage carcass is intended on the same conveyor.
- Definition of a separation scheme based on force control through a robot program.
- Drawing the systems solution showing the overall sub-systems in a robot integrated design.

Cost of the solution as a commercial system and projected returns are estimated, and a follow up AMPC proposal has been submitted.

5.0 PROJECT OUTCOMES

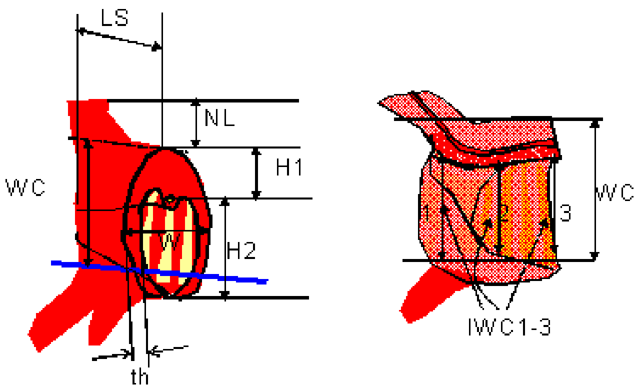
Progress of the project has been according to contract and on time.

5.1 Lamb shoulder primal variability

The measurements defining the variability have been reviewed (based on past measurements) and the process steps defined using video recordings of current practices. Measurements on carcasses in the range 15Kg to 40Kg (Figure 5.1) have been reviewed.

Figure 5.1: Carcass range 15Kg-40Kg

Figure 5.2 presents the feature in the shoulder primal pieces considered relevant and significant to the specification of the intended deboning process. The measurements of key carcass features provide the basic data for the specification of mechanisms and automated cutting program including sensory functions to guide achieve the process.



Kg	Weight of whole carcass from which the measured shoulder originated
L	Length of whole carcass from which the measured shoulder originated. Measured from the hook position to the bottom of the neck with carcass hanging from the hook.
WC	Width of cut measured from the back of the shoulder to the position of the cut separating shank and brisket
NL	Neck Length
H1	Distance between the back and the centre of spinal cavity
H2	Distance between the centre of the spinal cavity and the tip of the brisket
W	Widest width of the shoulder
Th	Thickness of the shoulder

IWC	Internal distance between the edge of the brisket and the position of cut as marked by WC. This is done in three positions 1, 2 and 3 to show the profile of the spine
LS	Length of shoulder measured from the rib cut position to the bottom of the neck

Figure 5.2: Measurements specification corresponding to features relevant.

The main variability in dimensions influencing the deboning steps include (See Table 1):

W - the overall width which varies by 40 mm about the main axis of the spine, with minimum width being 210 mm and maximum 290 mm,
LS - the overall length ranging 135 mm to 230 mm.
H - Effective height excluding neck section ranging 265 mm to 335.

Review of shoulder primal size variation									All in mm			
Item	Kg	L	WC	NL	H1	H2	H	W	th	IWC 1	IWC2	IWC3
1	16.7	1010	200	100	65	220	285	210	25	95	105	115
2	16.7	1040	200	120	65	215	280	230	110	105	110	135
3	17.2	1100	215	140	65	220	285	200	95	120	130	140
4	17.2	1100	215	135	65	220	285	220	95	120	130	140
5	18.7	1110	215	130	70	220	290	220	105	120	125	130
6	18.4	1050	200	110	70	235	305	230	100	105	115	125
7	19.1	1110	210	130	75	230	305	230	105	105	115	125
8	19.7	1110	220	120	76	235	311	260	110	105	116	125
9	20.7	1070	210	120	75	230	305	230	110	105	115	125
10	20.8	1190	230	110	65	200	265	215	100	130	140	150
11	21.2	1110	220	110	75	225	300	250	110	115	125	125
12	21.7	1120	220	100	65	230	295	220	95	105	120	135
13	22.4	1165	230	120	80	240	320	220	95	135	140	150
14	22.5	1180	230	120	80	235	315	225	100	125	135	150
15	22.8	1150	230	110	70	230	300	230	90	130	135	145
16	23.6	1130	210	110	80	230	310	260	95	115	125	135
17	24.2	1120	230	110	85	245	330	230	110	115	125	135
18	24.9	1110	210	110	75	230	305	270	105	110	120	130
19	25.9	1130	220	120	80	230	310	240	100	110	115	125
20	26.1	1110	220	100	80	225	305	240	100	110	115	125
21	26.6	1170	240	140	80	225	305	290	100	115	120	130
22	26.9	1180	235	110	80	245	325	270	100	130	135	140
23	27.3	1170	220	120	85	235	320	280	90	125	130	140
24	27.7	1150	240	110	85	240	325	250	90	125	135	140
25	27.3	1220	230	140	95	235	330	285	90	110	120	130
26	25.1	1200	230	120	90	240	330	285	100	110	120	130
27	28.6	1130	230	130	80	225	305	280	100	115	125	135
28	29.9	1140	230	120	95	225	320	240	110	130	130	135
29	30.2	1120	240	120	85	240	325	290	120	125	130	140
30	36.1	1240	240	115	90	230	320	270	120	130	140	150
31	36.8	1250	250	130	85	250	335	265	110	120	130	140

Table 1: Measurements presenting the variability in shoulder primal pieces from carcasses 15Kg - 40Kg in relation to features in Figure 5.2 relevant to de-boning.

5.2 Shoulder deboning process

The processes of meat separation from a shoulder primal pieces have been examined using information and observations from plant visits. Figures 2.1 and 5.3 presents the main manual processes observed.

Note that Figures 2.1 and 5.3 correspond respectively to the options for a fully deboned shoulder and that, where the remaining rib cage has the main eye muscle left attached to the spine and featherbone for production of shoulder cutlets.

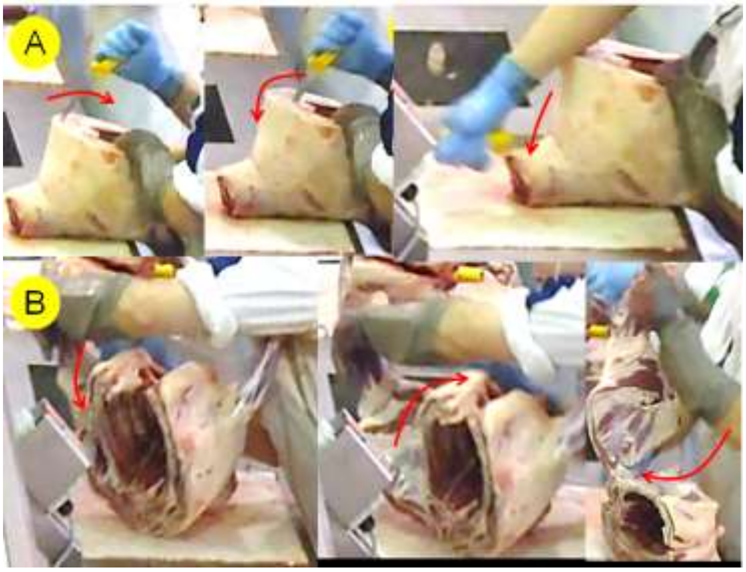


Figure 5.3: A - Cuts are parallel with the featherbone centre line leaving the eye muscle attached and B – separating "banjo", without the need to make the cuts as in Figure 2.1 (A).

Figure 5.4 provides the schematic summary of the cuts for automation, where the featherbone cuts are made, separating the eye muscle to the back of the shoulder primal, followed by the cuts from below the foreleg and brisket direction, separating the banjo and the whole of the shoulder meat from the primal piece: leaving the ribcage carcass with neck attached. Note in both cases the operation is repeated for the left and right sides of the whole shoulder primal.

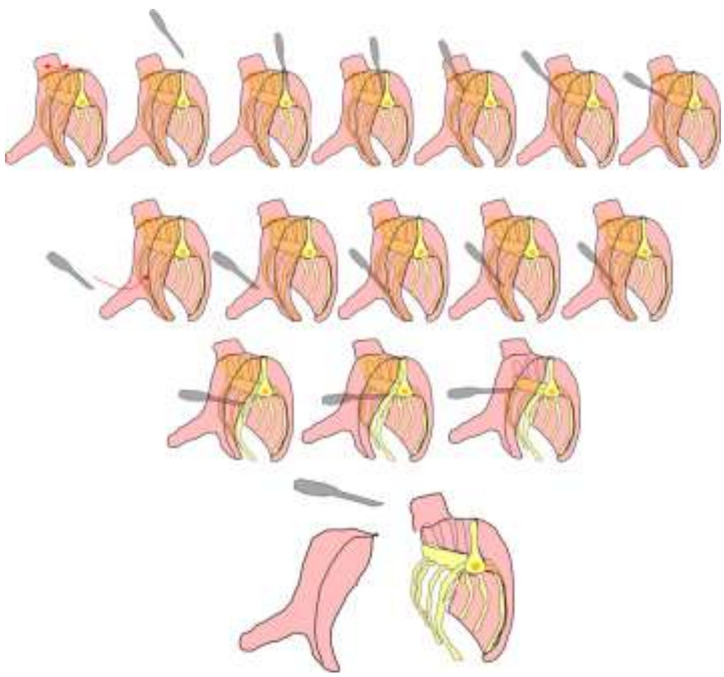


Figure 5.4: Start from top left and follow through left to right. Cutting scheme for full shoulder de-boning- note the pre-cutting along the seam of the 4th shoulder is not considered a necessity.

5.3 Cut paths, tools and variation considerations

Figure 5.5 highlights complications for a cutting blade that could provide the means for separating the meat from shoulder carcasses of variable size and complex rib cage profile. It is necessary that the cutting operation separates meat from the featherbone along the spine section (see Figure 5.4, top left). It is also necessary to separate meat from the spine itself and from the 4th or 5th rib cut plane all the way to the neck, and along the 4th rib, and over the ribcage following the profile of the ribs to the 1st rib: as in the manual process.

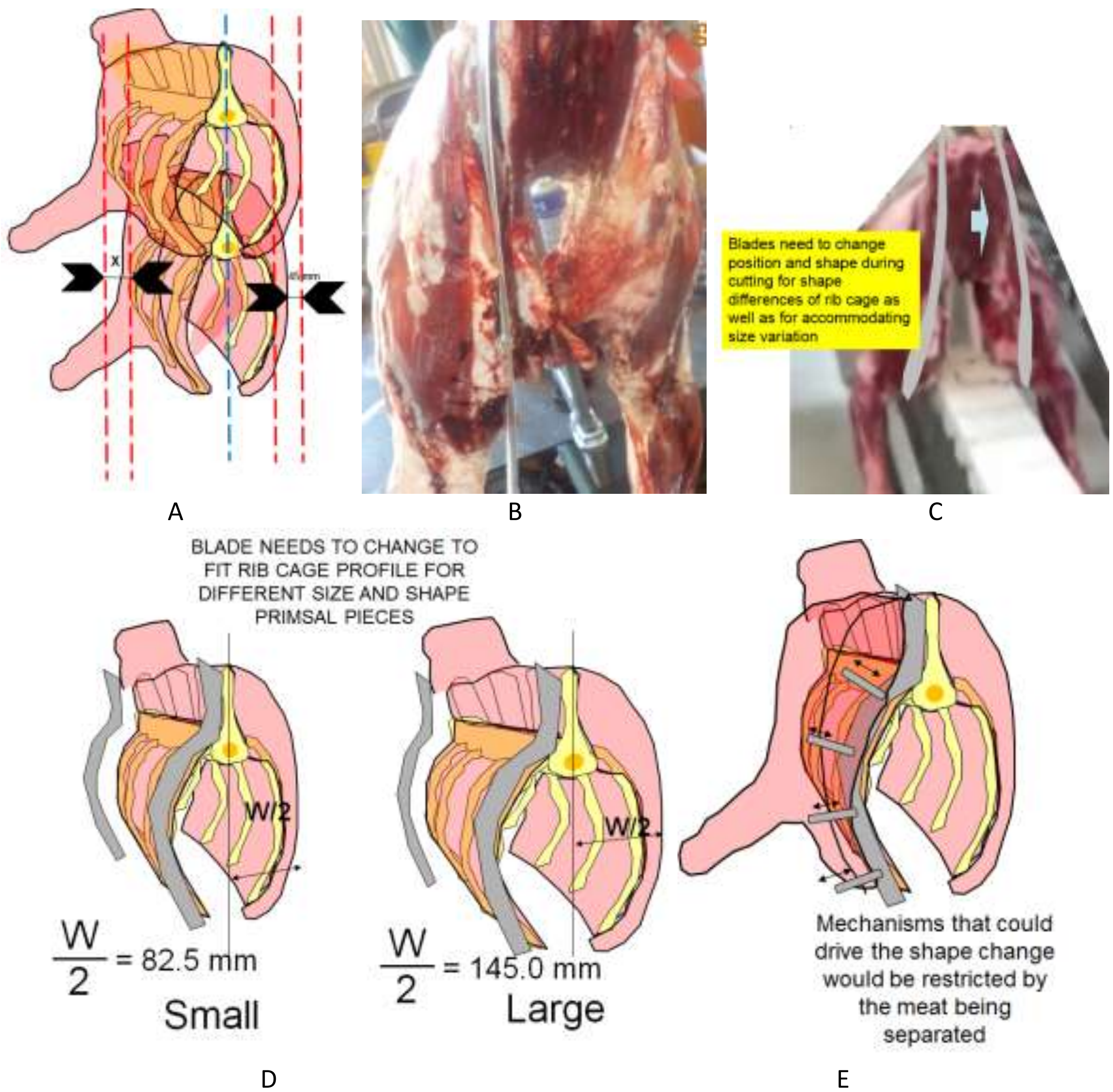


Figure 5.5: Complexities of following rib cage shape with shape blades.

The variation in shoulder ribcage sizes, especially between a large and a small primal, *W* in Figure 5.5A, is about 90 mm, which is 45mm relative to the centreline of the spine. *X,* which is the position variation at the cut entry point between the foreleg and the brisket, for large and small primal pieces is another important variable, and of the same order of magnitude in value as *W*. With a cutter approaching from the neck direction towards the 1st rib, initiating meat separation, the cutting tool entry point needs to accommodate a 45mm variation in position from primal to primal.

Figure 5.5B shows the profile of a blade at entry point of a cut to separate shoulder meat from the rib cage. Figure 5.5C illustrates the schematics of the same, mapping the tool on a primal piece as if it were being driven into the blades out of the image on a carrier conveyor as may be seen on an ATTEC machine. The illustration of Figure 5.5D, presents the challenge highlighting the complication for a shape changing blade that would be needed in conjunction with an ATTEC type machine carrying the primal into the blade. The constraint is the accommodation of the variability in the primal pieces, whist changing the shape of a bendable blade using drive mechanisms that allow the cutting edge to form its separating edge over the surface of the ribcage. The illustration of the schematics of the concept and the complications dealing with large and small shoulder primal pieces, where the blade needs to change shape is given in Figure 5.5D and 5.5E. The basic data together with the assessment of the required automatic process suggest that the specification the mechanisms and machine features require greater dexterity both in handling and separation capability in order to accommodate for the range of variability. It is also envisaged that size, positional and force (during deboning) sensory functions, to guide the tools that can perform separation, would be required.

The automation approach needs to consider other forms of handling and cutting, different in nature to those that may be based on ATTEC type machines using a carrier conveyor with self-guiding cutters.

5.4 Approach to automation using robotics

Automation approaches in many meat processing applications are focused on using robotic capability as this provides the most flexible manipulation, handling and grasping capability.

Figure 5.6 shows the approach for cutting a shoulder primal. A robot holds and drives the shoulder piece against a blade (see link to Scott Technology http://scott.co.nz/meat-processing/lamb/automated-boning-room-systems).

The Scott approach may be considered a possibility, where such an arrangement would allow the primal piece to be sensed and the robot guided to drive the shoulder primal against fixed blades, manipulating the shoulder in such a manner to achieve the desired separation for de-boning. The steps in the process would also require sensing for identifying and attaching to the shoulder primal as well as additional holding and fixation devices to support the cutting operation.

Figure 5.6: Robot holds shoulder primal, driving it against fixed blades to perform de-boning (Scott Technology solution).

A qualitative evaluation, reveals the following:

- The manipulation process would need to have significant dexterity, with considerable sensing capability to define in real-time the robot paths for each cutting action in 3D space,

- // The separation over the complex surface of the ribcage would demand high level of information processing in real-time,
- // The cost of the system and payload of the robot could constrain adoption as would the space requirements, based on the existing solution, which have been shown to work for square cut shoulder cutting (Figure 5.6).

An alternative is the to use a customised cutter tool attached to a robot, similar to a hand tool, with a handling system that is loaded manually delivering the shoulder primal to the robot for de-boning, similar to the leg de-boning solution by Scott Technology (Figure 5.7).

Figure 5.7: Leg deboning by Scott Technology.

The proposed approach is illustrated in Figure 5.8, with shoulder primal piece manually loaded in a posture that allows it to be scanned with simple sensing, and requiring minimum manipulation of the separated or cut meat.

The cutting knife on the robot would have appropriate compliance to allow the knife to be pressed against the bone structure of the featherbones, the spine as well as the ribcage, without cutting into bone, but following the bone profile closely, whilst separating meat. Such a solution has been previously implemented using a light weight robot for chicken breast separation from the wishbone by Khodabandehloo. It is also envisaged that the final solution would also include force sensing at least in the prototyping stage of development.

The approach in pursuing the approach of Figure 10 is that a more universal solution for de-boning may be reached. The steps for shoulder de-boning require the following:

- // Definition of a fixation and handling system for shoulder primal.
- // Definition of a robot system for performing the cuts
- // Integration with simple sensing to provide cut start positions relative to each shoulder primal in the range that deals with all sizes of Lamb and potentially Ovine shoulder primal pieces.
- // Implementation of a pilot to prove the concept as valid with costings.

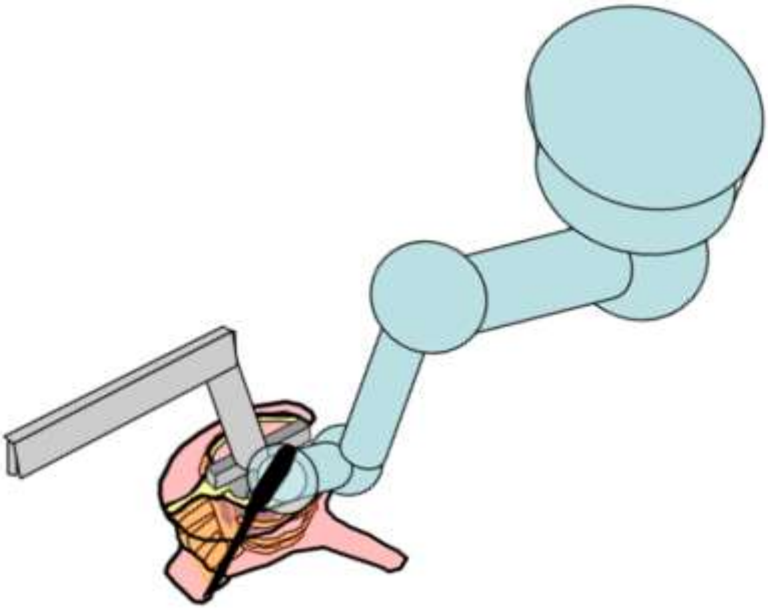


Figure 5.8: Proposed concept using a robot with appropriate reach to perform the cuts.

The overall consideration for reaching a blueprint of the design needs to solve the primal piece handling as well as the process by which the shoulder primal is transferred into the correct position, maintaining its orientation for de-boning. The description of the blueprint in the next section provides the approach to the solution, that is practically evaluated in manual workshop trials to be feasible.

5.5 The feasibility based on robotics

Figure 5.9 presents the steps in the process of de-boning, using a series of cutting steps.

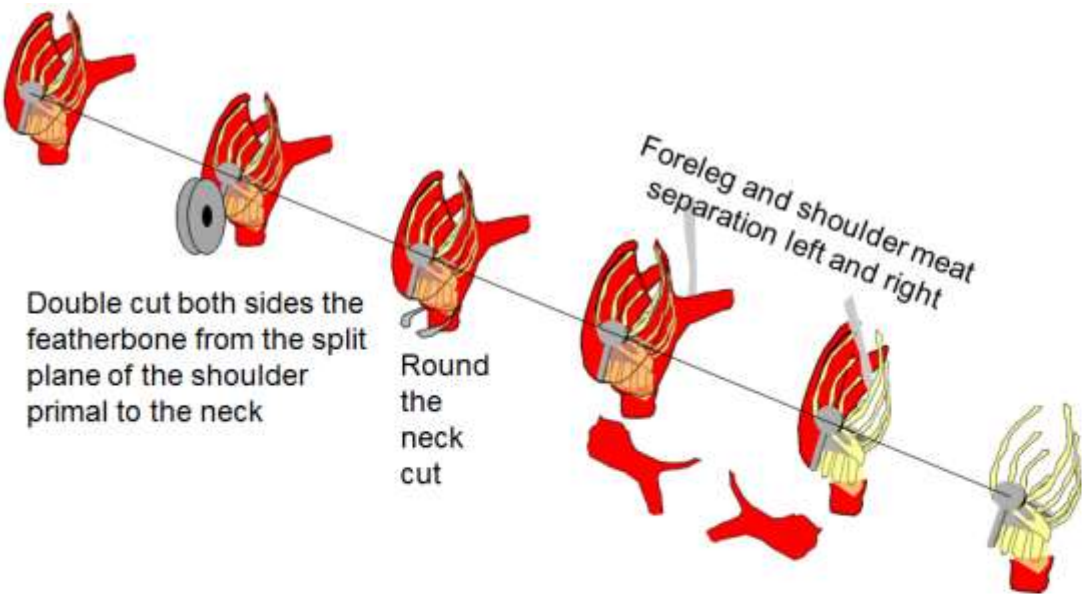


Figure 5.9: Shoulder de-boning automation steps.

The steps (Figure 5.9) in the process would be:

- Primal shoulders are conveyed from previous stage of cutting,
- Operator performs basic checks for quality and if needed trim the shoulder,
- Operator loads a fixture which holds the primal piece, as shown in Figure 5.10, in the spinal cavity and under the spine from inside the carcass approaching from the split face.

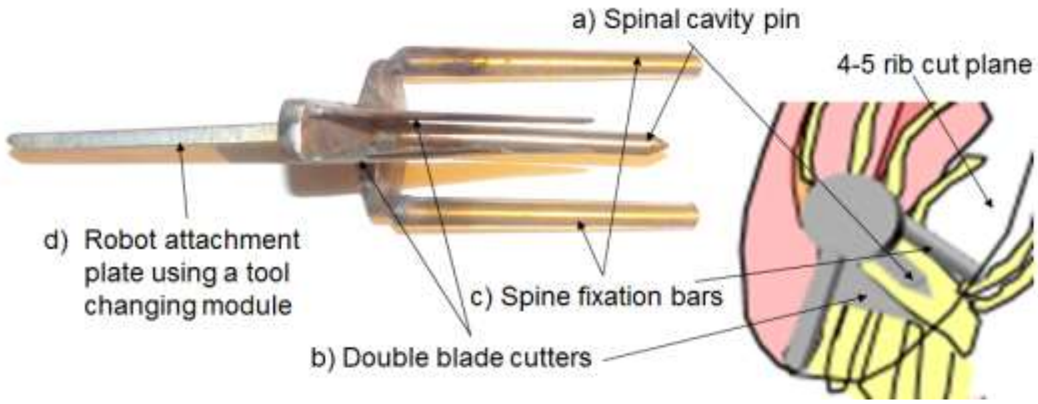


Figure 5.10: Fixation solution.

- A robot in the conceptual integrated cell arrangement of Figure 5.11, may perform the cutting actions for deboning as shown.

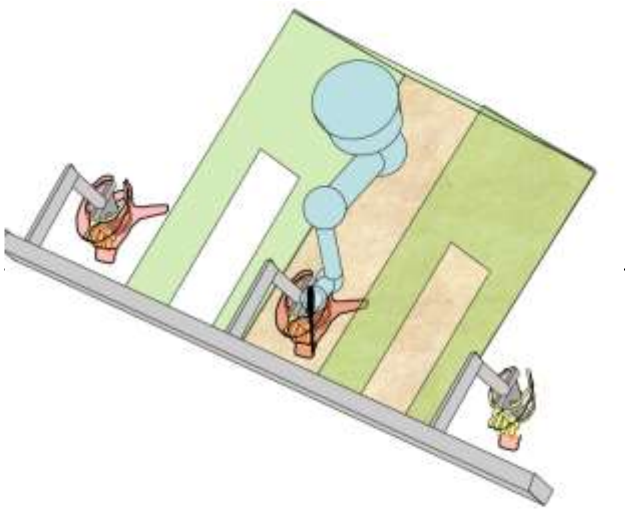
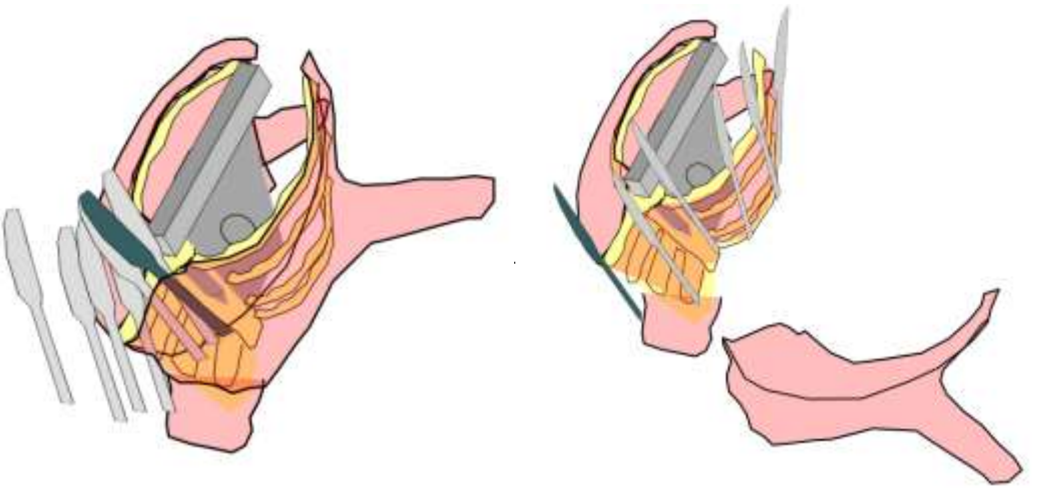


Figure 5.11: The approach for automating shoulder de-boning.

The main elements (Figure 5.11) would include the following:

- a standard low cost robot adapted for use in a wash-down environment,
- a fixation solution that provides for location and referencing the carcass. Note: such a solution has already been developed by BMC and used in the ATTEC shoulder machine and presented in Figure 5.10.

- a handling system that delivers the shoulder primal pieces from a manual loading position, through a safety fence and light curtain system, for the robot to perform the task of de-boning using the scheme illustrated in Figure 5.12.
- Cutting knife that provides for meat separation adjacent to bone with compliance capability in the tool attachment connecting to the robot as well as the blade. Note: the tip design would need to be based on the aforementioned wishbone-breast meat cutting blade developed by BMC chicken breast filleting.



5.12: Scheme for robotic de-boning.

Figure 13 shows results of trials in a workshop environment supporting the robotic approach.

Figure 5.13: Trials in support of cutting scheme for robotic rib-cage separation.

The options for designing a handling solutions may be based on a carrier arrangement, where an operator loads a fixture of a saddle shape mandrel or a custom made chain and gripper arrangement. A conceptual set up is shown in Figure 5.11.

In the approach to considering the design for such a fixture a more flexible solution with features that reduce the complexity as well as the cost for automation is realised using a second robot that performs the process of handling using the simple fixture of Figure 5.10. This is elaborated in the next section.

5.6 Blueprint of the solution and the approach to implementation

Figure 5.14 shows the Blueprint of a twin robot solution that is proposed for prototype development and would achieve de-boning of lamb shoulder primal pieces from carcasses in the range of variability 15Kg-40Kg.

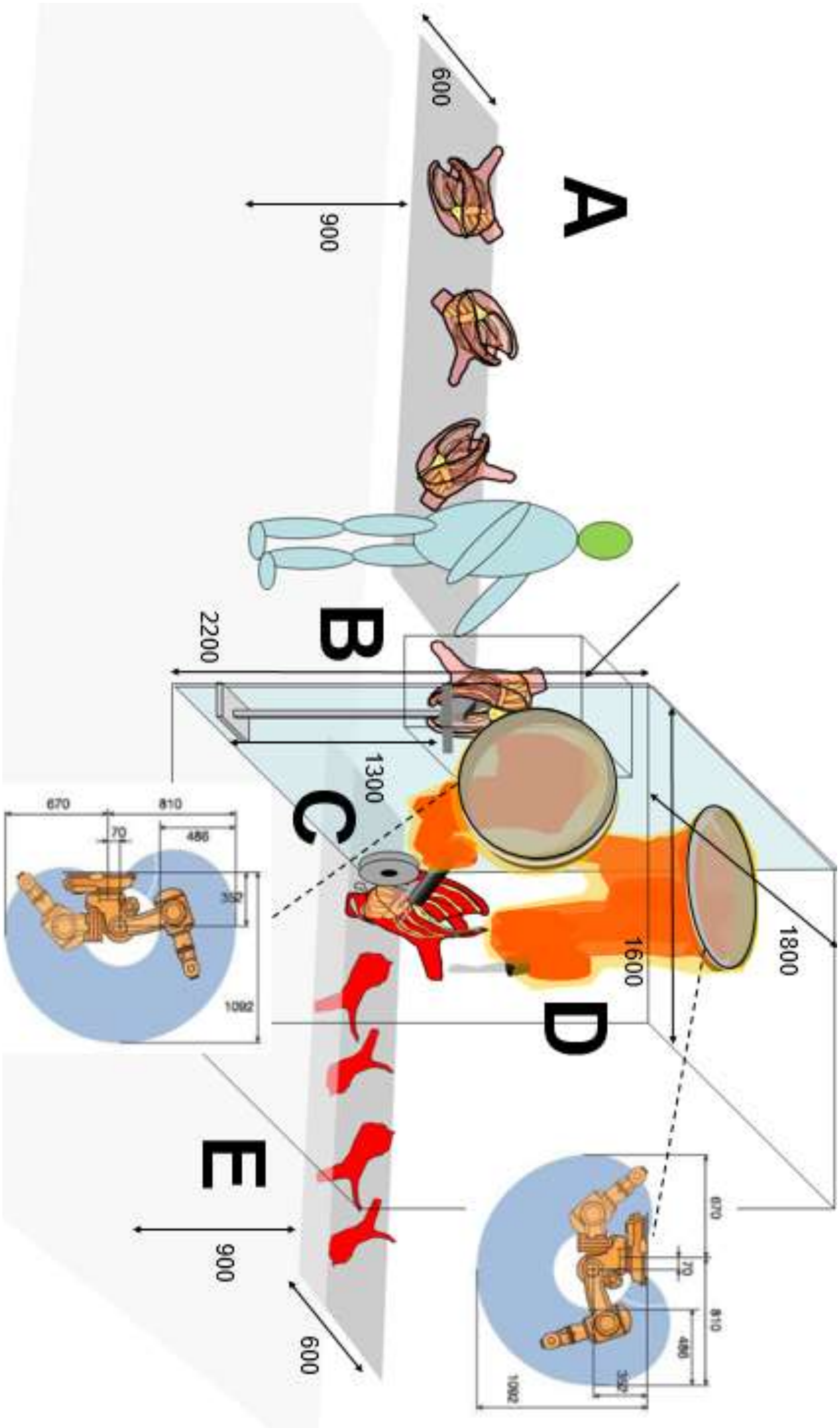


Figure 5.14: Blueprint of Shoulder de-boning solution.

The method of fixation for the shoulder primal is presented in Figure 5.15. This is loaded manually at the robot station entry (Figure 5.15B).

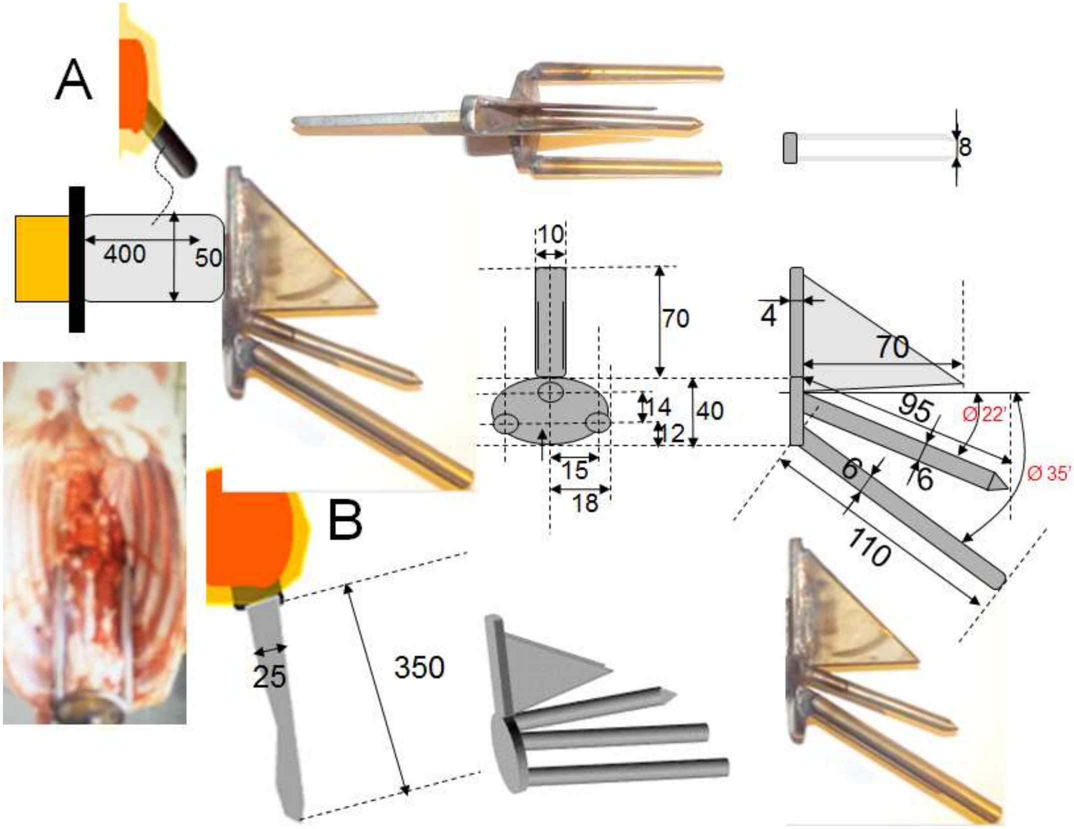


Figure 5.15: Fixation details, robotic tools and primal piece locating.

In the 'blueprint' of Figure 5.14, the features and the operating steps would be:

a) Carcasses arrive on an infeed conveyor 600 mm wide belt and 900 mm high with adjustable legs with height adjustment in the range ±150 mm to suite the handling ergonomics for the operator.

b) The operator loads the Fixture (Figure 5.14B), which is clamped on a stand, at the spinal cavity pin location 1300 mm above ground. This allows the shoulder primal to be located as shown in Figure 5.10, with the spinal cavity pin (Figure 5.10a) inserted, the double blades penetrating either side of the featherbones (Figure 5.10b), and the spine, at the 4th or 5th shoulder rib cut plane, resting on two parallel 'spine fixture' bars (Figure 5.10c) locating the primal piece as shown (also in Figure 5.15 bottom left).

c) A robot (Figure 5.15C) use the fixture, (Figure 5.10d) transferring the fixture and positioning it securely whilst holding the shoulder primal in the robot cell. A guarding system is required to ensure operator entry is restricted into the robot area including hand and arms.

d) At the cutting point C, Figure 5.14, a pair of rotary cutters using the edge of the fixture double blade cutters (Figure 5.10b), to make a deep incision both sides of the feather bone to the neck. A scissor cutter performs the cutting around the neck. This is followed by robot cuts using a plane cutting knife as Figure 4B. The cutting actions would use force sensing (Figure 5.16) and follow the separation process shown in Figure 5.17. The cutting starts to the side of the brisket edge (Figure 5.17 top left). The subsequent cuts would proceed with the edge and tip of the blade forced against the rib cage with an oscillation action that separates the meat, controlling the applied force of the knife using a 6 axis load cell.

The cut paths would be defined by the robot program, with the force control adjusting the trajectories to achieve the end result as illustrated by Figure 5.17 (top left to top right and down as a raster sequence), resulting in the shoulder meat and foreleg separated fully (bottom right image, Figure 5.17).

e) The separated shoulder and foreleg sub-primal pair, as well as the ribcage carcass would be released on a 600 mm wide, 900 mm high conveyor to exit the Twin Robot Cell.

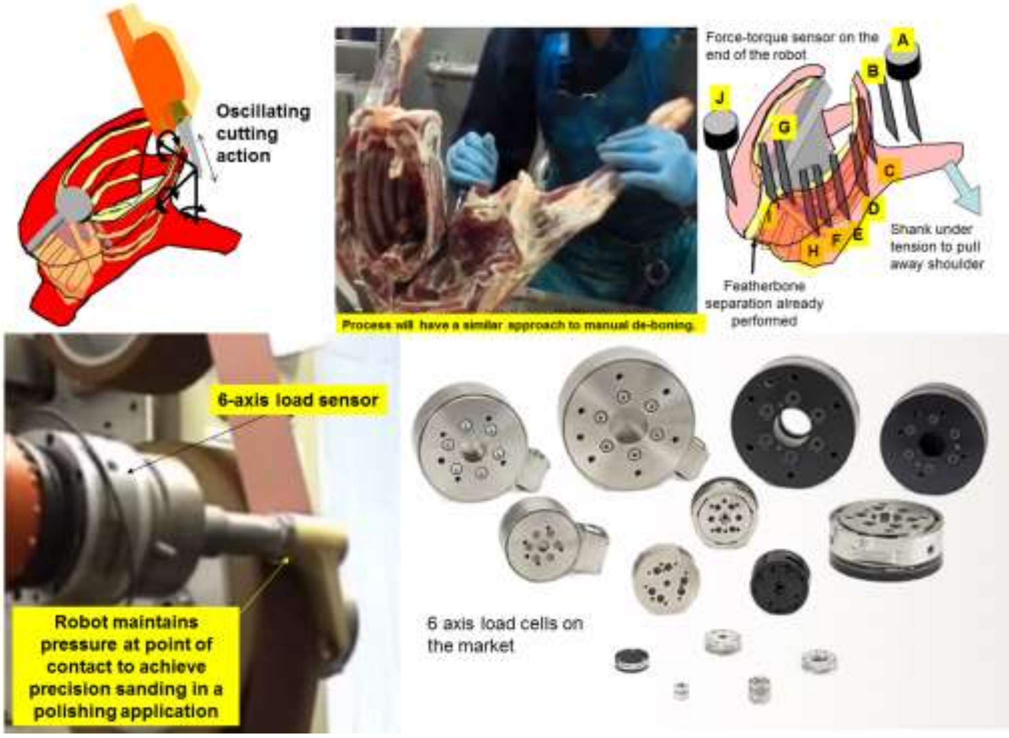


Figure 5.16: Force control using standard 6-axis load cell between the robot tool flange and the knife (see Figure 5.15B).

Figure 5.17: Sequence of cutting actions.

6.0 DISCUSSION

The feasibility of the ribcage deboning of lamb shoulder primal process has been examined in detail by this project and considered practical based on the results to date.

It will be necessary that the developments take into consideration important development stage especially with respect to sensor integration and robot programming.

The process of bone/meat separation at the interface of ribcage profile may use the techniques developed by Maddock and Khodabandehloo in the late 80s (also presented in a publication: Robot deboning for beef forequarters, G. Purnell, N. A. Maddock and K. Khodabandehloo, Robotica, Volume 8, Issue 4, October 1990, pp. 303-310- https://www.cambridge.org/core/journals/robotica/article/robot-deboning-for-beef-forequarters/C08514A1D04A03A0921FE3A75BBAAAC1). The de-boning would be based on the integration of a 6-axis force sensor with an ABB Robot. Such sensors are standard (http://www.ati-ia.com/Products/ft/sensors.aspx?gclid=CJTu7P2Mp9MCFYZjvAodAywHpA), and commonly integrated with many robots including ABB robots (Figure 5.16 bottom left).

It is important to state that the robot program requires a number of iterations in its implementation. Several stages of experimental manual teaching (moving the robot through cut paths using the robot manual pendant, used by a robot programmer) is required, in order to gauge the reaction forces and reflected torques from the sensor carrying the knife.

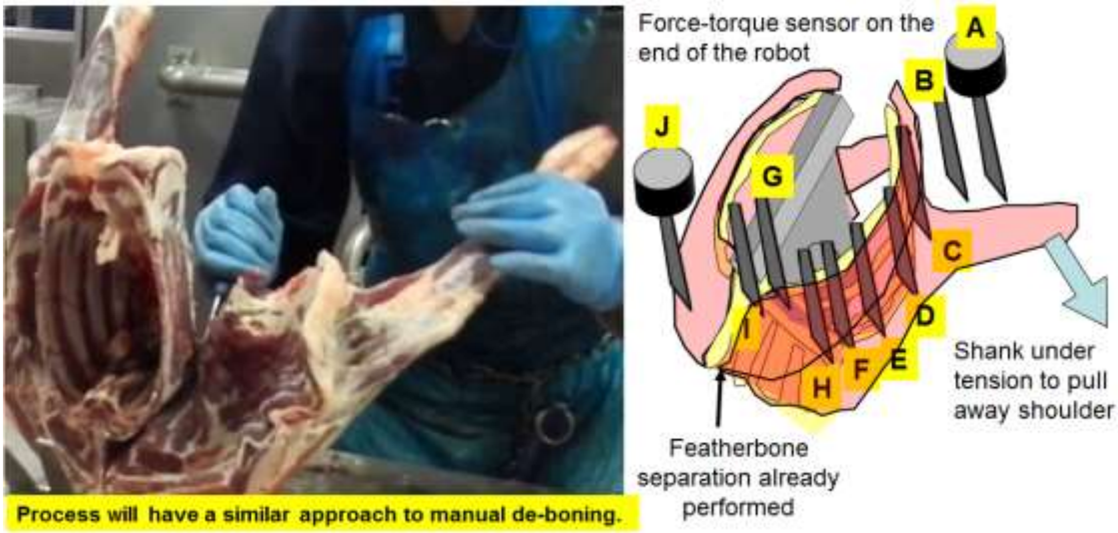


Figure 6.1: Programming the robot path with trajectory changes to maintain close knife contact with the ribcage during the separation actions of the robot.

Once the programming is achieved, and with reference to Figure 6.1 (right of the image), the knife movements would be similar to that of a butcher and as follows:

A) Point of approach at robot point fixed relative to the fixation allowing for carcass position, ensuring a clear distance.

B) Interim position to orientate the knife relative to the shoulder primal (a laser scanning of the primal would provide coarse, (±10mm, positioning of the entry point for the knife if the passive positioning proves inaccurate).

C) The knife is driven into the meat until a line of contact is made with the ribcage (edge of the knife and not a point contact). This is achievable by sensing the reaction force from the knife, when it makes contact with bone having cut through the meat. The orientation of the blade is then to be altered by the robot using torque information from the sensor to align the knife parallel to the rib cage.

D-E and F) show the direction of the cut with an oscillating action in the line of the knife whilst following the rib cage maintaining a force and torque on the knife to keep its edge and, where appropriate, only the tip, in contact with the ribs, whilst, if necessary, the shoulder is pulled away by a secondary mechanism from the rib cage similar to the manual process (Figure 5.18 bottom right) The shank may be required to be under tension).

G) on reaching the line of the spine at the end of the ribcage, the path would follow the line of the spine through to the base of the ribs to point G, followed by a secondary knife pass along the path H-I.

H-I) During the move from H-I it is anticipated that the knife tip would run parallel with the spine as close to the seam between the featherbones and the spine, applying a controlled force to achieve meat separation.

J) The knife would exit and clear the primal piece after shoulder and foreleg separation in one piece.

The process would repeat for the other side.

Programming the above requires experimental robot teaching and path trajectory modelling on several shoulder rib carcasses in order to acquire the range of force-torque data and path profiles.

The costing for the solution is updated and presented in Table 1.

Shoulder De-boning twin robot cell costing			
70,000	2x robots	70,000	Unit labout cost
18,000	wash down adaptation	2	People saving estimated
8,000	In-feed conveyor	140,000	Annual saving on 1 shift
5,000	Operator loading station	23	Months ROI
6,000	Safety booth at loading point		
20,000	Safety guarding and interlocks		
18,000	Robot controller cabinet		
3,000	Fixation unit		
6,000	Robot gripper tool changer		
17,000	Double cutter		
15,000	Neck clamp		
8,000	Outfeed conveyor		
30,000	Robot programming		
25,000	System integration		
249,000	Sub-total		
24,900	Contingency		
273,900	**Total of for a commercial system after prototyping**		

Table 2: Estimation of cost and ROI for a shoulder rib-cage de-boning solution of Figure 5.14.

7.0 CONCLUSIONS/RECOMMENDATIONS

The measurements show variability of the shoulder primal in overall dimensions and in specific feature positions important to the design features of the intended elements of a deboning machine, including knife blades for rib-cage separation.

The examination of the process of deboning points to a new development requiring a solution for separation of the rib-cage from the main muscles of the shoulder, leaving the boning of the forelegs and the shoulder blades in one piece, with the shank attached, from the remaining sub-primal pieces.

The project has successfully reached a potential approach towards the implementation of a shoulder deboning solution using robotics that are based on similar technological capabilities already proven for shoulder cutting and de-boning.

A ‘blueprint’ for the proposed solution has been produced and the key elements evaluated. Relevant equipment has been researched and the technologies needed for the implementation of the Twin Robot System as in Figure 5.14 are readily available.