AUSTRALIAN MEAT PROCESSOR CORPORATION

# FINAL REPORT - Desk Top Review in to Collaborative Robot Applications in the Red Meat Industry

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# 1.0 Executive Summary

A desk top review of current collaborative robot applications both within the red meat processing industry and other industries, such as the automotive industry, was undertaken. Collaborative robots that are currently on the market were briefly examined and compared to determine the current industrial applications of collaborative robots can be grouped into four major categories including; parts assembly, pick and place operations, quality control and hazardous tasks. The implications for applying collaborative robots in the red meat processing industry were accessed in terms of product consistency, nature of sensing, control systems, safety and hygiene.

Following consultations with red meat processors, potential automation tasks within plants were identified, while existing and alternative processing scenarios were examined. The advantages and benefits for using collaborative robots, instead of traditional industrial robots to automate the tasks identified were detailed in terms of the ease of implementation into existing process flow, the range of integrated sensor hardware, and intuitive reprogramming.

Furthermore, potential meat processing tasks for collaborative robot trials were investigated based on value and feasibility. Specifically, the value of collaborative robots to the meat industry compared to traditional industrial robots was examined and potential tasks were selected based on feasibility. Ideas for future research relating to collaborative robots is also detailed in this report.

# 2.0 Market Analysis

## 2.1 Industry Challenge

While the costs of traditional robotic systems have come down, as technologies become cheaper, there are still many peripheral costs associated with the supporting systems that are required for an automated solution to function. These include safety measures, integration into existing production systems and auxiliary components that help automate/control the robot, such as sensors. Integrating automated systems into commercial meat processors often require substantial remodelling of the production line. Furthermore, it is often a requirement that the plant maintains production during the proposed robotic system integration.

The ability to reduce costs whilst improving OH&S practices and maintaining productivity is viewed as advantageous to all meat processors around Australia. The challenge is to maintain a safe working environment while increasing the productivity of meat processing facilities. These challenges have inevitably led to a push to automate many of the processes in the red meat industry.

At present there are large opportunities for use of automation technology within the meat industry. Most, if not all, meat processors use some form of automatic assistive technologies, such as conveyor systems to transport primal cuts and trims from the boning stands and slicing tables to the final weighing and labelling stations in preparation for packing. Irrespective of this, the bulk of processes within the meat industry remain manual.

At present there are many new collaborative robots emerging in the market which are changing all the preconceived thoughts about robotics in industry. Their main feature is the ability to interact and work safely alongside human workers while performing repetitive, hazardous or heavy lifting industrial tasks. In the past, robots have always been large robust devices that work only on specific tasks for which they were designed. For safety reasons they were brightly coloured and surrounded by fences and guards to isolate them from surrounding workers. High level programming skills were required to get these industrial robots running, and would need to be reprogrammed and possibly repositioned within the factory to undertake a new task.[1] [2]

While many of the processes in the industry are already being automated, there currently exists no solution to provide a safer working environment, flexibility and cost effectiveness in the red meat industry all in a complete package.

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[1] Jane Shi, Glenn Jimmerson, Tom Pearson, and Roland Menassa. 2012. Levels of human and robot collaboration for automotive manufacturing. In Proceedings of the Workshop on Performance Metrics for Intelligent Systems (PerMIS '12). ACM, New York, NY, USA, 95-100.

[2] Collaborative Robot EBook, (2013), 3rd ed. RobotIQ, http://blog.robotiq.com/collaborative-robot-ebook

## 2.2 Existing Solutions

Collaborative robots on the market today have up to 7 degrees of freedom (DOF). This is one more than necessary, but it allows for advanced configuration of the robot arm. Some collaborative robots come with 2 robotic arms attached to a central torso which houses the controller. These robots are designed to be more like human workers and can include a display on which the robot can show expressions. Both arms can act independently or cooperatively to perform various tasks. In terms of the red meat industry collaborative robots have not been utilised as they are a relatively new technology and are still quite expensive.

**Figure 1: Gomtec Roberta**

### 2.2.1 Current Collaborative robots

### Single arm collaborative robots:

- IIWA from KUKA

IIWA is based on a human arm with 7 DOF; it has a weight of 30 kg with a payload of 14 kg and a 1300 mm reach. It can fulfil delicate jobs due to its built-in high performance collision detection algorithms. Relatively slim and low weight, it can work in tight spaces and it can be integrated on assembly lines quite easily. However it is not as easily programmed as the other collaborative robots shown here, requiring some basic programming knowledge.[3]

**Figure 2: KUKA IIWA**

- P-Rob from F&P Personal Robotics

The P-Rob has 6 DOF, weighs 12 kg and has an operating range of 800 mm; however its payload is only 1.5kg. It is easy to program and monitor with most smart phones, tablets and laptops able to control the different aspects of this collaborative robot. The software architecture is focused on adaptive behaviour. The robot can improve its performance based on feedback due to its deep learning network, including neural and Bayesian probability network algorithms. The P-Rob is designed from soft material with rounded shapes, and integrated with forces limiters and stop functions to work safely around humans. This collaborative robot comes with different peripherals, such as a camera and a movable base. [4]

**Figure 3: F&P Personal Robotics P-Rob 1R**

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[3] http://www.kuka-labs.com/en/service_robotics/lightweight_robotics/

[4] http://www.fp-robotics.com/en/prastandard/

- Roberta from Gomtec

Roberta has 6 DOF, weighs about 20 kg, with a reach of 800 mm and a payload up to 8 kg. This collaborative robot comes with graphical user interface software and is very intuitive to program through this interface or by demonstration. The wrist joint is equipped with an illuminated rotating ring which provides information about different points or motions and is a safety feature alerting workers of the robot's different statuses by showing a colour-coded acknowledgment.[5]

**Figure 4: Rethink Robotics Baxter**

- Speedy 10 from MABI robotic

Speedy-10 has 6 DOF, weighs 28 kg, with a reach of almost 1400 mm and a payload of 10 kg. This robot is based on a lightweight design and offers high precision positioning for high-speed applications due to a high-resolution absolute feedback encoder. The robot is controlled through an intuitive graphic user interface.[6]

- UR5 and UR10 from Universal Robots

UR5 and UR10 both have 6 DOF with a payload of 5 and 10 kg, weight of 19 kg and 29 kg, and reach of 850 mm and 1300 mm, respectively. Programming is primarily done through demonstration, manipulating the robotic arms and using the touch screen tablet to record the trajectory. In case of collision, the robot has force limiters which limit the amount of force to a safe level around humans.[7]

**Figure 5: MABI Robotic Speedy 10**

## Dual arm collaborative robots:

- Baxter from Rethink Robotics

Baxter also comes with a LCD screen for a "head" which can display facial expressions. It has two 7 DOF arms, each with a payload of 2.3 kg and an integrated camera for detecting parts. Its total weight is 75 kg without the optional pedestal which allows the robot to be transportable. All the required controllers are integrated into the "torso". The main concept behind the design of Baxter was for it to require no programming at all, instead a worker teaches tasks to the robot.[8]

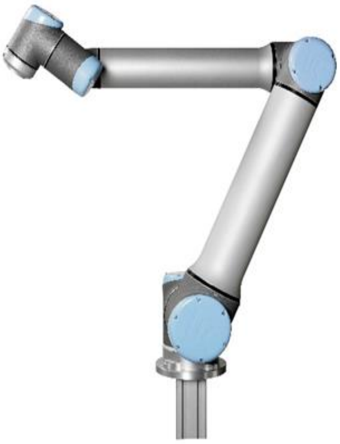

**Figure 6: Universal Robots UR10**

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[5] http://www.gomtec.de/

[6] http://mabi-robotic.com/en/speedy/speedy/

[7] http://www.universal-robots.com/GB/Products.aspx

[8] http://www.rethinkrobotics.com/baxter/

- Nextage from Kawada Industries

Nextage's overall design includes a "head" with two cameras for stereo vision, two 6 DOF arms, as well as a "torso" and mobile base which contains the controller. The "head" also has 2 DOF which allows it to adjust its field of vision. This robot has a combined weight of 130 kg and each robotic arm can lift a payload of 1.5 kg. Each arm is equipped with a hand camera that can capture 3D information of an. The software uses a graphical user interface for which the source code is freely available to the general public.[9]

- Workerbot from pi4 robotics

Workerbot comes with a LCD screen for a "head" which can display facial expressions and is equipped with two vision cameras and an optional time-of-flight 3D camera capable of facial recognition. It has two 7 DOF arms, Each with a payload of up to 10 kg and despite a total weight of 500 kg, it remains transportable due to its mobile base which contains its controller. This collaborative robot is reconfigurable and programmed with the graphical user interface supplied.[10]

### 2.2.2 Current applications in other industries

Collaborative robots have been integrated into a range of large industries, including automotive and semiconductor industries. However the biggest impact collaborative robots have had is on smaller companies, such as Etalex and King Innovation, where previous large scale automation wasn't feasible.


Figure 7: Kawada Industries Nextage


Figure 8: Pi4 Robotics Workerbot

In bigger industries the advantage of collaborative robots over traditional robots is the smaller overall size without the need for safety isolation fencing and guarding, as well as the increased dexterity in terms of what the robot can manipulate and what motions it can perform. This allows the collaborative robots to be integrated into existing assembly lines where space is limited. Collaboration between robots and workers is primarily observed with so called intelligent assist devices or power amplifying assist devices, where the robot lifts the part and is guided by a worker within a programmed virtual surface.[11] In the automotive industry this is used for assembling heavy and cumbersome parts such as

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[9] http://nextage.kawada.jp/en/

[10] http://www.pi4.de/english/systems/workerbot.html

[11] J. Krüger, T.K. Lien, A. Verl, Cooperation of human and machines in assembly lines, CIRP Annals - Manufacturing Technology, Volume 58, Issue 2, 2009, Pages 628-646

the windscreens and doors. The initial cost of the robot or the programming requirements are less of an issue in larger industries.

For smaller companies, collaborative robots may provide a cheaper and more flexible alternative to traditional robots. Because additional safety guarding does not need to be installed around the robot it can be integrated more easily into the factory and with lower start-up costs. The collaborative robots can be programmed to perform a specific task for a short period and then be easily relocated and reprogrammed to perform a separate task as production requires. [12] This allows the company to fully utilise the capacity of the collaborative robot by moving it to where it is needed most at that time, something which is infeasible with traditional robots. Some of the tasks currently performed by collaborative robots include:

- Parts Assembly;

  Using two robot arms to position and then assemble very basic components, or using specially designed jigs or other automated machines, such as riveting machines or automated presses, to assemble and join components (Lear Corporation)[13].

- Pick and Place;

  Including sorting components, bin picking, loading and unloading from automated machines (GENCO)[14], transferring parts from one assembly line to another (King Innovation) [15], and packaging products (The Rodon Group)[16].

- Quality control and product inspection;

  Utilising integrated cameras included with several collaborative robots to inspect products and perform various quality control tasks within automated assembly lines (Nordic Sugar)[17].

- Hazardous tasks;

  Including various welding operations, use of electromagnetic radiation (such as lasers or sterilisation equipment), and tending to potentially dangerous machines such as brake presses (Etalex) [18] or stamping machines.

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[12] http://www.universal-robots.com/en/case-stories/etalex/
[13] http://www.universal-robots.com/en/case-stories/lear/
[14] https://www.youtube.com/watch?v=0xNqtwW_qn0
[15] https://www.youtube.com/watch?v=6PSCTiBi6KY
[16] https://www.youtube.com/watch?v=qL64UyYRBYg
[17] http://www.universal-robots.com/en/case-stories/nordic-sugar/
[18] http://www.universal-robots.com/en/case-stories/etalex/

### 2.2.3 Case Study: BMW production group – South Carolina

**Figure 9: BMW collaborative robot[30]**

BMW production group has decided to incorporate collaborative robots into their Spartanburg, South Carolina plant in an effort to provide a work environment where robots could assist the current workers with a select number of jobs around the plant. Currently BMW has implemented a pilot of one such robotic system, supplied by Universal Robots, that is used to assist workers in the application of sealant onto door assemblies. The operation previously required foil with an attached adhesive to be inserted into the door assembly and then pressed by human operators using a manual roller. It is considered to be a very strenuous task, and a high risk for repetitive stress injuries[19] for the workers due to the physical effort required coupled with the need for extreme accuracy.

Upon consultation with BMW's head of innovation, Stefan Bartscher, the introduction of the collaborative robot system into the plant is because they "actually need something to compensate and keep our workforce healthy, and keep them in labour for a long time. We want to get the robots to support the humans[20]." The realisation of longevity in the workforce can be seen as the inspiration to adapt this new technology and provide safer working environments for the employees.

Julie Shah, who is a professor at MIT, is also working on the BMW plant installation and has major plans for future expansion. According to Julie the outcome of the pilot project undertaken by BMW has identified two major points for further development, one being the formulation of new technical specifications and safety standards for robots in a working environment, and the other being the ability to provide more compact lines due to the removal of barriers between robots and humans[21].

Julie is also currently working on developing a model for 'cross-training' which involves teaching the robots a simulated model of human behaviour, so they can react to the human environment factors instead of following pre-programmed paths. However, it also involves training the operators to model how the robots will behave to ensure full synchronization of robot and human.

The collaborative robot pilot was considered a successful implementation by the BMW group and further applications of collaborative systems are being investigated, with BMW planning on performing an upgrade of similar existing plants to the new collaborative setup. Stefan Bartscher commented on the pilot by saying "We regard the successful implementation of ergonomically optimized human-robot

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[19] http://articles.economictimes.indiatimes.com/2013-12-27/news/45627047_1_robots-jeff-burnstein-automation

[20] http://www.technologyreview.com/news/518661/smart-robots-can-now-work-right-next-to-auto-workers/

[21] http://www.automotivemanufacturingsolutions.com/process-materials/intelligent-automation

cooperation in series production as a major step toward future automotive engineering and the world of Industry”[22].

## 2.3 Influencing Factors

The acceptance of automation technologies into the red meat processing sector is dependent on a number of influencing factors. Which include:

### 2.3.1 Technological Limitations

To meet safety requirements for operating around human workers all collaborative robots come with integrated sensors for collision detection and automatic stop or reverse functions. This includes position sensors, force and torque sensors, or sensor to detect an over current in the motors. Several collaborative robots come with integrated vision systems for product identification or as an added safety feature to detect nearby human workers. These integrated vision systems include image recognition control software and generally offer open source software libraries for research applications. In terms of the red meat industry, due to the irregular shape of the products, additional sensors or more complicated vision systems are likely to be required.

Several collaborative robots have integrated control systems, allowing them to be moved around a factory easily and some even come with mobile bases. However some collaborative robots still require an external control cabinet. All collaborative robots are designed to simplify the programming of the robot, either with an intuitive graphical user interface or through demonstration by a worker manipulating the robotic arm to the required positions. Teaching by demonstration allows the robot to be programmed by anyone and requires almost no programming experience. Most collaborative robot systems can be operated as a standalone system, but they still offer standard digital or analogue inputs/outputs to accommodate a range of sensors and additional peripherals. Real time information on the robot can be analysed alongside existing equipment by integrating into existing information management systems using USB or Ethernet connection protocols.

### 2.3.2 Financial Considerations

As standalone items, collaborative robots are significantly more expensive than traditional industrial robots. On the order of $100,000 for a good quality collaborative robot versus $30,000 for an industrial robot on comparable load and size capacity. However a standard industrial robot as a standalone item is just a very expensive and excessively large paper weight. An industrial robot needs an End-of-Arm-Tool (EOAT), a sensor network to provide feedback to a custom written robot program, as well as numerous safety features such as safety guarding and light curtains to operate anywhere near other human workers. Depending on the complexity of the task being automated, these additional costs can make collaborative robots a more feasible option because they already have some integrated sensors and don’t require safety guarding. However this can only be determined on a case by case basis.

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[22] https://www.press.bmwgroup.com/global/pressDetail.html?title=innovative-human-robot-cooperation-in-bmw-group-production&outputChannelId=6&id=T0209722EN&left_menu_item=node__5247

Another factor that contributes to the financial outlook of a robot cell is labour reduction. The average annual cost of a boning room employee including wages and on-costs was found to be around $50,000. This would lead to a saving of around $100,000 per annum if two operators were taken over by a robotic cell which could run numerous shifts a day. This would also eliminate the amount of workers compensation claims and other health and safety related costs that are being paid by the company. There may be some on-going costs related to the running of a robotic cell, such as maintenance, utilities and servicing. However, these costs are minimal compared to the potential gains of a robotic cell.

### 2.3.3 Quality

Examples of collaborative robot applications in other industries rely on consistent products in terms of size, shape and weight, when performing repeatable tasks. They primarily either require precise positioning of components prior to being picked and manipulated, or they utilise vision systems to identify the component and then position to pick it up accordingly. Red meat products and processes are not consistent and can have large variations in size, shape and weight. Additional sensing or intelligent gripping tools would be required to allow inconsistent products to be handled reliably and repeatedly.

### 2.3.4 OH&S

As Collaborative robots are required to work in close proximity with human workers they must be correctly configured and chosen to meet standards, which include ISO 10218 and AS 4024.3301. However as it currently stands collaborative robots are severely lacking in safety protocols, with most being able to detect forces using only simple methods such as monitoring motor current. The technology is available to develop greater safety features, although as collaborative robots are new to the manufacturing and food processing industry a re-evaluation and improvement of current safety standards should be developed first, to force robot manufacturers to address the OH&S concerns of the market. Safety could be achieved through a range of integrated sensors to detect and prevent collisions, cameras to identify human workers, and smooth rounded edges on the outer casing to avoid jamming points. While collaborative robots are designed to minimise hazards in the workplace, there may be additional hazards that cannot be prevented or are introduced by the introduction of a robotic system, such as electrical hazards.

### 2.3.5 Market Acceptance

Industrial robots are becoming more widespread throughout a range of industrial applications. They are designed to perform repetitive tasks with relatively high speed and accuracy, however are often large and difficult to move. The benefits that they bring to industries are often not enough for some companies to accept into their existing production lines.

Collaborative robots are designed to be compact, lightweight, dexterous and flexible. They have integrated sensors and software as safety features. If the robot detects a collision or that the external forces are too high, the robot will stop its movement or move in the opposite direction to avoid any injury.[23]

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[23] Collaborative Robot EBook, (2013), 3rd ed. RobotIQ, http://blog.robotiq.com/collaborative-robot-ebook

The majority of collaborative robots can be programmed by demonstration instead of having to write lines of code or run complex simulations. They can therefore be implemented very easily and don't require installation of fencing or guards. They can also be moved around the factory with ease in order to perform another task at a different station.

### 2.3.6 Hygiene

Examples of collaborative robots in other industries do not represent the required hygiene standards required in processing red meat products. Most collaborative robots come with only basic dust and water protection, if any, and would require additional protection to allow for high pressure cleaning or application of caustic chemicals to maintain hygiene standards. This would generally involve using a pressurised robot suit to prevent contamination and protect the robot during cleaning. Meat processers are subject to some of the strictest hygiene standards, and any proposed automation solution must first demonstrate its ability to comply with these standards. The Australian Standards require:

- Cleaning compounds to be approved for use in meat processing premises
- All chemical residue to be removed from sources likely to contaminate edible products by thorough rinsing with water before the area or equipment is used for handling edible products (unless it is approved for use without a final rinse).

### 2.3.7 Minimal required work area

Without the need for large protecting fences and safety guarding, collaborative robots can operate in a lot smaller work spaces. They can be incorporated more easily into existing manufacturing operations that are tight on space, such as the meat processing industry. Due to their integrated safety features that can also work in very close proximity to human workers, that's what makes them collaborative robots. Many collaborative robots have 7 DOF, which is one more than is required for complete translational and rotational movement. This additional degree of freedom gives the robot arm more dexterity and flexibility to reach into tightly constrained spaces, such as into an internal cavity of an animal carcass. The robot is able to control the position and orientation of the tool as well as the configuration of the rest of the robot arm. This means that the robot can move and operate in very tight spaces and within the work envelopes of other robots and human workers.

# 3.0 Technical Feasibility

## 3.1 Potential Tasks

The potential tasks are separated into hot side and cold side. This list is only a general guide of the tasks that could feasibly be automated in a generic red meat processor.

### 3.1.1.Hot side

- Belly cut – The belly cut is fairly uniform, and can be done by existing robots, but must be very precise so as not to puncture the offal and contaminate the carcass. In-built force sensors could be utilised by a collaborative robot to provide real time feedback and produce more precise cuts, however a vision system would still be required to identify the placement of the initial cut. The development of a safe tool for use by the robot would be required to allow safe operation around human workers without the use of guarding or other safety measures.
- Break leg bones – The force required to break the leg bones may be beyond the capabilities of current collaborative robots. However, if a collaborative robot was able to provide the necessary force, it would be suitable for automating this process due to the integration of force sensors into the robot arm providing necessary feedback during the bone breaking.
- Brisket cut – Due to the unpredictable size of each animal, the brisket cut will need additional recognition equipment on current robotic systems to generate a tool path for the robot to cut the brisket. Although it is still feasible for a collaborative robot to repeatedly make this cut, provided the load restrictions are not exceeded by the weight of the tool.
- Femur bone removal - Due to its distinct shape the leg can be easily recognised by vision or by feel, however depending on the size of the animal the payload restrictions may be an issue when removing the bone, especially due to dynamic loading on a collaborative robot. The integrated sensors provided by collaborative robots may be useful but not necessary for this task.
- Head removal – This is a feasible task as the head is readily identified using vision sensors on the collaborative robot, giving them a distinct advantage over stand-alone robots. Generating the tool path required to precisely remove the head may not be possible with the software supplied with the collaborative robot due to the variations between individual cattle. Additional software and programming of sensor may be required to successfully automate this task.
- Hide removal – The cutting and removal of the hide could be suitable for a collaborative robot with appropriate force sensors and vision systems. The force sensors can be utilised to ‘feel’ the path through the fat layer to remove the hide. With the appropriate vision system and software, the tool paths for the hide cuts at the start of the removal process can be generated.
- Hock removal – The hock can be easily identified by existing sensor technologies on collaborative robots due to its size and shape, making it a feasible task. The removal of the hock is independent of the size of the animal and will be uniform and easily repeated by a collaborative robot. Provided an appropriate tool can be developed and operated by the collaborative robot it could be integrated directly into the production line without much modification.

- Tail removal – As long as the robot is capable of repeatedly grasping the tail of the animal, the tool path will by similar to all the other removals. Therefore this is quite feasible with given technologies.
- Evisceration – The evisceration process is quite in-depth and intricate, and therefore the robot will need to be equipped with a special tool to complete the process and make this feasible, without missing anything that could lead to condemnation of the carcass. However the additional DOF provided by the extra joint axis provides some collaborative robots with the ability to reach into the internal cavity of the carcass. This would give a collaborative robot significant advantage over a traditional robot for this task. This would potentially be a good ‘collaborative’ task where a human and a robot could work together on this operation. e.g. a human could assist or remove anything missed by the robot. The collaborative robot’s ability to ‘feel’ it’s way through the internals of the animal would also make it an adept choice for tackling the automation of this task.
- Inspection of offal – The offal is normally examined by inspectors, in order to determine which parts are appropriate for consumption by the public. This requires that a health standard is met in regards to approval of the offal. As such a complex combination of sensors and recognition software will need to be incorporated into the robot system to meet these standards for this to be feasible. The vision and force sensors that are incorporated into some collaborative robots make them more suitable for quality control and inspection tasks than traditional industrial robots.
- Quarter cut – This cut will be fairly easy to accomplish for a collaborative robot with an attached vision system. Assuming there isn’t any load limitations this task would be suitable for automation with collaborative robots.
- Spinal cord removal – The irregular shape of the spinal cord combined with the precision that is required for this type of operation makes it fairly difficult, but feasible. The robot would require sensing technology to be able to generate an accurate tool path for the cutting tool (or at least starting point) but could also be assisted by being able to ‘feel’ it’s way down the spine.
- Scribing – The scribing process can have considerable effect on the consumer end of the market provided the efficient utilisation of the carcass. Therefore it is reasonable to assume that the sensing hardware and software that would need to be added to a collaborative robot system for this to be feasible will need to be considerable.
- Trimming – As this is quite a delicate process the tool used and the path generated by the robot must be fairly precise in order to complete this process and minimise waste. Vision systems and other complex sensing technologies would be required. However this is also a task where collaboration between a worker and the robot would be beneficial, allowing for the cutting to be fully or partially automated. A collaborative robot, equipped with a suitably safe retractable knife may be quite adept at this task due further to its ability to feel its way through fat to be trimmed, recognising the different resistances posed when attempting to cut fat, muscle and bone.

### 3.1.2. Cold side

- Bagging and sealing – The ability of a collaborative robot to cooperate with and complement other human or automated systems can be utilised in this process, given that it has been programmed effectively. The sensing required for this task doesn’t need to be incredibly precise but does need to be very reliable. The use of a collaborative robot for this task allows for more flexible automation compared to traditional industrial robots. In the event that the robotic system cannot complete the task, either the meat isn't identified or it is incorrectly bagged, an operator can easily rectify the situation, even within the robot workspace, without halting the production line.

- Boning – Force feedback from the robot arm could be used to simulate how human workers feel their way through the fat line, separating muscles and bones, in the boning process. This would allow collaborative robots to assist with the automation of many tasks in the boning room, but would require further research and development into the method of generating tool paths from force feedback. This may be easier than providing algorithms, which are used in conventional robotic systems.
- Picking and packing – Picking and packing is a common industrial robotic application in broader industry. The feasibility of a collaborative robot to perform this task is dependent on its ability to adapt to the variation in products. It may also be feasible to introduce several collaborative robots to pick and pack a few product types only, which utilises their advantage over current robots. Alternatively, collaborative robots could be used to pack only specific cuts, such as the largest or heaviest, while a human worker packs the remaining cuts within the same workspace of the robot. Packing rooms are usually quite tightly packed with people, conveyors and cartons so collaborative robots may come into their own in this environment.
- Quality control inspection of primal cuts – Anything that involves manual inspection of the product in order to meet the standards set for the food processing industry, will require a high degree of accuracy. For this to be feasible it will need to be able to identify the quality of each product with a 100% success rate and will most likely require an elaborate network of sensing technologies. Some collaborative robots have integrated vision and or sensing technologies that would be required for quality control inspection, making them more suitable than traditional systems. And can use 'feel' (force based sensing) in conjunction with vision systems and collaboration with humans.
- Trimming – Same as above for trimming on hot side.

## 3.2 Processing Scenarios

### 3.2.1 Continuous line

The majority of meat processors operate with a continuous line chain where the carcasses are hung from an overhead rail that transverses the entire plant. Workers are positioned at stations along the line and have one or two specific tasks to complete on each and every carcass before it progresses to the next station.

The line chain can be operated with either continuous motion or stopping and starting at each station. For a plant operating with continuous motion, the workers have to make cuts or perform other procedures on the carcass as it is moving. Alternatively, the line chain can be operated to stop at each work station for a designated period of time before moving on to the next station.

The disadvantage for automating a continuous line process is the potential for large periods of idle time. If only one task is going to be automated, then the cycle time is still limited by the human workers and the robot will potentially be idle for a large portion of the cycle. Since each station only performs one specific task, and unless consecutive tasks can be easily combined, the robot will not be fully utilised.

### 3.2.2 Cellular

Cellular processing involves individual cells where multiple tasks are performed on the same stationary carcass. Depending on the size of the processor, this can be achieved by a single worker per cell who may even completely process a carcass from start to finish. This allows machines and operators to run at varying speeds, instead of being fixed to the speed of the continuous line chain in the method above. Equipment and personnel can be fully utilised by allowing each carcass to be processed individually, maximising yield and performing quality control immediately.

A cell based approach allows for the carcass to remain static or restrained during processing. This would be advantageous for automation allowing greater processing accuracy. This may also allow for more cost effective automation of certain processes. Furthermore, cellular processing is beneficial for robotic implementation as the system won't suffer from high idle time as in a continuous line system. Collaborative robots enable a hybrid system to be created, where both human operators and robots could work safely and efficiently together in the one cell, as shown in Figure 10.

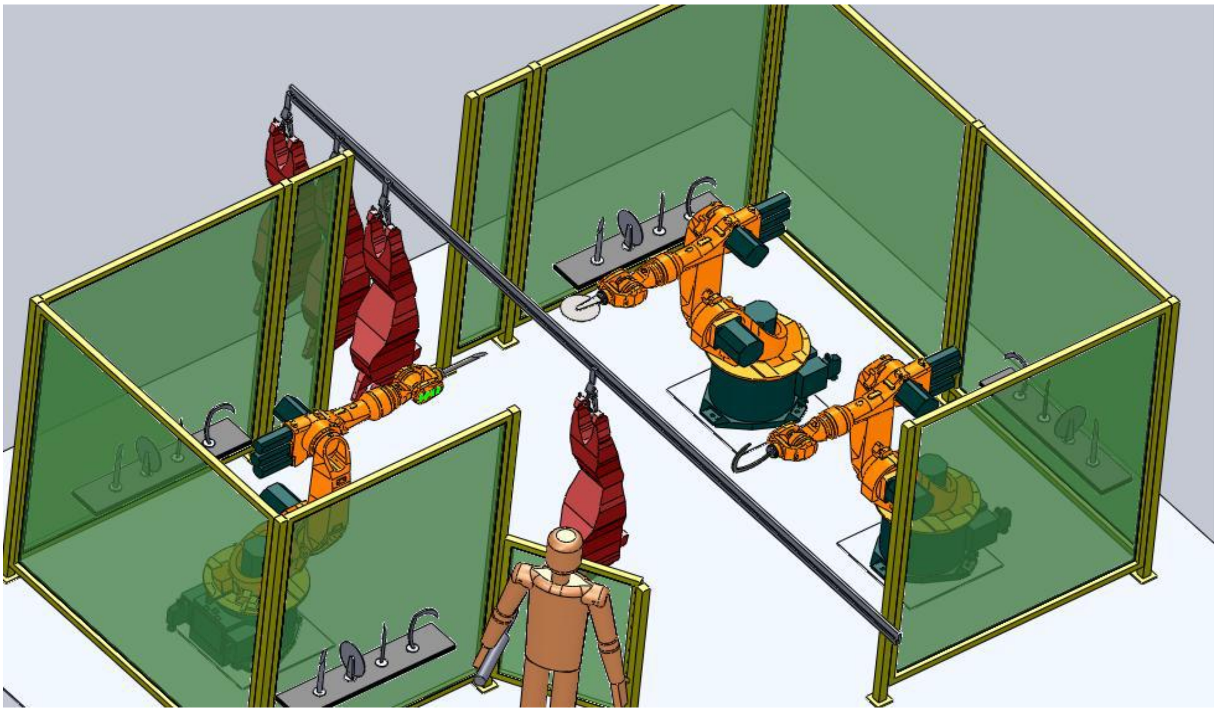

**Figure 10: An illustration of a single production cell featuring industrial robots.**

The robot would perform simpler, potentially heavier or more dangerous tasks. Leaving the more specialised and difficult tasks, in terms of sensing or control, to a human operator. A human operator could also perform trouble shooting, quality control and rectification of issues associated with the robot activities that may otherwise be infeasible to automate.

This processing method presents several challenges, particularly in terms of maintaining hygiene standards, and requires more extensive training of the workers to handle multiple tasks, including cutting, trimming, inspecting and packaging.[24] However, total production capacity of the processing plant is more flexible with a cellular based processing scenario, as additional cells can be installed or manned as required to meet demand.

### 3.2.3 Batch

Batch processing is another alternative process flow where specific tasks are completed on batches of carcasses. For instance, one specific cut or operation is made on each carcass in the batch. After the operation is performed on all carcasses in the batch, the next required operation is then made on each carcass of the batch. This processing method is kind of a combination of continuous line and cellular.

Batch processing presents several challenges, especially if the batch size is required to be very large to make it feasible. For instance, if a carcass is taken out of refrigeration to make a single cut, and then returned to refrigeration until the next batch, a lot of time and energy is wasted in moving back and forth between batches. Furthermore, the space required to store each carcass in a batch is comparable to the space required for a continuous line process, but with a much lower production rate.

The advantage of batch processing in terms of automation is the ability to fully utilise a robot for processing. A single robot can perform the task required for one batch. After completing the batch, the robot tool can be changed and program updated to perform the task required in the next batch. This way the same robot is used for multiple tasks. If all tasks cannot be automated, those tasks can be completed by human workers without stopping or slowing down the robot.

## 3.3 Advantages of Collaborative Robots

From an automation standpoint, there is no difference between an industrial robot and a collaborative robot when it comes to automating these potential tasks in red meat processors. Both kinds of robots operate under the same basic principle of computer controlled motion. Both industrial and collaborative robots require a programmed controller, an end of arm tool and a system of sensors providing feedback to accurately and repeatedly perform a task. The potential benefit that collaborative robots have to the red meat processing industry is that they can be integrated into existing meat processors more easily than standard industrial robots. Also, they have a lot of the additional sensor hardware built into the robot and they are more easily and intuitively reprogrammable.

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[24] G. Heinz, “Abattoir Development: Options And Designs For Hygienic Basic And Medium-Sized Abattoirs”, Animal Production and Health Commission of the United Nations, 2008

### 3.3.1 Integrated sensors

Due to the inconsistent nature of meat products, automation of any tasks in meat processors tends to require advanced sensing systems, such as force feedback sensors, high definition vision systems, 3D cameras, laser measuring systems, and ultrasound and x-ray scanners.[25] [26] Standard industrial robots do not come with any additional sensors or feedback systems. However, all collaborative robots have some integrated sensors as part of their safety features, and most also come with integrated cameras and force/touch sensors.

Several collaborative robots come with integrated cameras either on their “head” or attached to their “arms”, specifically designed for product inspection and quality control tasks. This reduces the number of additional hardware components required for implementing specific robotic solutions into meat processors. However, the out of the box software and feature recognition algorithms that accompany these integrated vision systems is insufficient for the variability of meat processing.

The difficulty involved in automating the majority of the processes in red meat processing is also the variability of the product. Currently available off the shelf vision and feature recognition systems cannot accurately and repeatedly identify the placement of the required cuts. Research has previously been conducted for generation of tool paths for robotic cuts using ultrasound and x-rays to detect bones and changes in the meat tissue. Another sensing mechanism uses force feedback to determine where to slice or cut based on the resistance in the different meat tissue.[27]

A lot of collaborative robots have force and touch sensors built into the end of the robot arm; some even have them on every axis joint. It should be possible to monitor the feedback from the force sensors and adjust the robot tool path as required to make more accurate cuts, even when the actual size or shape of the product varies. Force sensors can be installed on standard industrial robots, but a collaborative robot has the added advantage of being able to work with a human worker. Should any problems be encountered, an operator can be standing by to resolve the issue without any significant downtime.

### 3.3.2 Higher number of axes

A robotic arm requires 6 rotational axes to reach every pose within its work envelope, giving it 6 degrees of freedom (DOF). Many collaborative robots have an additional 7th axis which provides more flexibility of the robot to operate in confined spaces. The extra rotational DOF acts like the elbow joint in a human arm allowing the EOAT to move in a straight line close to obstructions. In a traditional 6 axes robot this type of motion is restricted as the arm of the robot would have to pass through the obstructions to maintain the trajectory of the EOAT.

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[25] Z. Li, A. Hinsch, “A new approach to Detect the Cutting Position for a Robotic Beef Carcass Scribing System”, ACRA, 2003

[26] G. Purnell, “Robotic Equipment in the Meat Industry”, Meat Sci, 1998, 49, pp 297-307

[27] I. H. C. Wadie, K. Khodabandehloo, “Path Generation for Robotic Cutting of Carcasses”, Comput. Electron. Agric., 1995, 12, pp 65-80

### 3.3.3 No safety guarding

The integrated safety features of collaborative robots make them safe to operate without any additional form of guarding to isolate them from human workers. This removes the additional cost of safety guarding and associated safety control and monitoring systems required for traditional robotic installations. Furthermore, the space requirements of a collaborative robot are significantly reduced due to the lack of safety guarding.

### 3.3.4 Robot worker interaction

The nature of collaborative robots allows them to not only work in the same workspace as humans but also directly with humans. This allows the robot to work as an assistance tool for the operator. The robot arm would carry the required cutting tools and the operator would directly manipulate the robot arm to perform the required cuts. Research has already been previously undertaken into specially designed machine assist devices. For example, Kinea design has looked into developing a hook assist system that can be used in the beef boning process to improve the ergonomics of the operation in an attempt to address some of the OH&S issues associated with the process. It involves the use of a machine that can be used by a human operator to lower the force requirements that are needed when boning the carcase.[28] Newer collaborative robots could be utilised as similar assistance devices for a wider variety of meat processor tasks.

Alternatively, an operator can assist the collaborative robot with a product that it cannot scan or identify for whatever reason. Or in the event that the robot breaks down or requires maintenance, a human worker can continue the robots job in the production line with potentially no down time. Downtime is a serious concern in automation using traditional industrial robots because of the way they are integrated directly into the production line. Human workers cannot quickly take over or correct the robots job due to the isolated safety guarding and any other modifications to the existing production line.

Conventional industrial robotic cells installed on continuous meat processing lines have the potential to halt whole lines and hundreds of workers should they complete an operation incorrectly. However when using collaborative robots, operators working with or in the vicinity of these systems have a much higher chance of being able to rectify individual errors caused by the robot on the fly. Due to the easily available methods for teaching/programming collaborative robots, co-working humans also may be able to correct re-occurring problems swiftly without the need for specialist engineering personnel. This may well be an advantage to plants located in remote areas.

### 3.3.5 Ease of reprogramming

One the selling points for collaborative robots is mobility and ease of reprogramming, allowing it to be repurposed as required by the production facility. It may be useful in bagging and wrapping or picking and packing tasks if these are done as groups of similar products.

For instance, a collaborative robot could be programmed to pick and pack one set of primal cuts for an order and then be reprogrammed to pick and pack a different set of cuts for the next order.

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[28] J. J. Santos-Munne "HookAssist development", Project code: A.OHS.0050, Meat & Livestock Australia Limited, July, 2011.

As the type of cut is likely to be packaged again in the future, this method is less efficient than simply programming different routines for the robot and then selecting the required one.

In a batch processing system, this reprogramming could be more useful. The robot could be programmed for one task that is run through for the entire batch, and then reprogrammed for the next task. Again, depending on the implementation and batch size this may be inefficient, and pre-programming all the tasks would be a better option.

## 3.4 Disadvantages of Collaborative Robots

The disadvantage of collaborative robots in the red meat industry can be attributed to the fact that most collaborative robots on the market are developed for other sectors in industry and not many are aimed at food processing. While some of the disadvantages listed below can be minimised, during the setup of the robot, many of them need to have serious modifications to meet the standards of the red meat industry.

### 3.4.1 Load restrictions

Compared to traditional industrial robots, all collaborative robots have very limited load capacity. Including payload limits as small as 2 kilograms, up to 14 kilograms as a maximum. Standard industrial robots, depending on the design requirements, have average payloads of roughly 30-90 kilograms with larger models available that can lift over 1000 kilograms.

The small payloads available on collaborative robots will limit the tasks they can automate in meat processors. For instance a collaborative robot would not be suitable to automate the carcass splitting or similar task, as it requires lifting an industrial bandsaw. Care needs to be taken when designing EOAT for collaborative robots to minimise the weight of the tool.

### 3.4.2 Hygiene requirements

Meat processors have strict hygiene standards which require washing of all equipment with harsh chemicals. Collaborative robots, like traditional industrial robots, do not have sufficient protection for exposure to harsh chemicals or elevated temperature and pressure wash downs. The solution for industrial robots in these environments is to put the robot in a pressurised suit that can easily be cleaned and prevents any liquids or foreign particles interfering with the sensitive electrical and mechanical parts of the robot. A similar pressurised robot suit would need to be purchased for a collaborative robot at an additional cost.

### 3.4.3 Inconsistent nature of product

One of the major selling points for most collaborative robots is the ease of programming of the robot, such as using a method of teaching to record the robot program. This type of programming is only possible on consistent products. In meat processing, the product is inconsistent, with every animal being unique corresponding to differences in the size, shape, weight, colour, etc. This is possibly the biggest challenge for automation in the red meat industry. It is possible that some collaborative robots do not have the capability to process the programming requirements demanded by the inconsistent products in the meat processing industry.

### 3.4.4 Additional safety issues

Although collaborative robots meet the required safety standards to operate around humans without safety guarding and other systems, the manufacturers still recommend undertaking a safety assessment of the robot system and to install safety guarding, even if it is not strictly required, to isolate the robot if it is not necessary for the robot to work within human workspace.

One reason for this is that to meet the safety requirements, some collaborative robot limit their speed when in the same workspace as a human. It is only when the robot is isolated by safety guarding like with a traditional robot that it can operate at its maximum speed. This may or may not be an issue in a meat processor depending on the task being automated, however it does limit the maximum capacity of the robot for future automation.

Another safety consideration is the nature of the EOAT. The majority of tasks in a meat processor require cutting tools. Even a “collaborative” robot wielding a razor sharp knife or saw is going to be a serious safety risk. This severely limits the type of tasks that a collaborative robot can be used for, without safety guarding, or requires the development of EOAT with their own integrated safety features, such as a retractable knife.

The disadvantage of collaborative robots in the red meat industry can be attributed to the fact that most collaborative robots on the market are developed for other sectors in industry and not many are aimed at food processing. While some of the disadvantages listed below can be minimised, during the setup of the robot, many of them need to have serious modifications to meet the standards of the red meat industry.

## 4.0 Feasible Tasks for Future Trials

The removal of large items such as hocks, heads and tails is ideally suited to collaborative robots. They are easily identifiable and located with existing vision technologies. Depending on the existing layout of the processing plant, it may be possible to install a collaborative robot into the existing station in the production line, with no additional control, sensory or safety system required.

Slightly more challenging tasks include the belly cut, brisket cut, spinal cord removal, feather bone removal, scribing of the carcass, quality control inspectional of the offal and quality control inspection of primal cuts. These are all tasks that have been identified to have potential to be feasible for collaborative robots, but will likely require additional hardware and sensors, or further research and development.

## 5.0 Research Areas

### 5.1 Force sensor feedback

The integrated sensors in some collaborative robots allow the Cartesian forces on the EOAT to be measure in real time. Force sensor feedback from the cutting tool as it progresses through the meat will give different readings depending on whether it is cutting through muscle, fat or even bone. This varying feedback could potentially be used to generate tool paths for the robot in real time. As opposed to pre-determining the path using external or penetrating sensors such as vision or ultrasound. Further research needs to be undertaken to determine if force sensor feedback based path generation is feasible and what meat processor tasks it could be applied to.

## 5.2 Retractable knife

To overcome the safety hazard of an unguarded robot wielding a razor sharp cutting implement, a retractable knife EOAT is proposed. To remain safe around humans within the workspace, such an EOAT blade would need to be extended only when in contact with the meat or a suitably isolated cleaning station. One possible way to achieve this would be to apply a small voltage to the meat, most likely through the line chain above. The safety system controlling the robot can only extend the cutting tool when contact is made with the meat, indicated by the initial flowing of current by the completed electrical circuit. Further research is required to ensure such a system is both technologically feasible and complies with the required safety standards.

## 6.0 Recommendations

Cellular production is mentioned above briefly and isn't normally considered a viable process due to problems involved with training, tool limitations and timing issues. However, the cellular process is most beneficial for robotic implementation, especially for collaborative robots. The ability of collaborative robots to complete multiple tasks, due to programming and intelligent vision systems, means the robot will not be affected by the high idle times experienced by a continuous line system. It is recommended that the processes involved with the red meat industry be further studied to assess viability of cellular production incorporating both human operators and collaborative robots.

A serious issue with collaborative robots is their failure to meet industry standards with hygiene. Provided collaborative robots are further researched in future endeavours, it is recommended that an economical solution is investigated to deal with the robots being deployed in harsh environments. Another recommendation would be to provide research into automation supporting technology for the red meat industry, such as vision systems and EOAT's designed for red meat processing. This would allow for a broader range of tasks to be completed by a collaborative robot and could be adapted for any automation system.

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