final report

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Investigating aviation security screening equipment in the meat industry.

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Executive summary

A large volume of previous research has shown that medical X-ray CT is a gold standard method for obtaining Objective Measurements in the red meat industry. However, medical X-Ray CT is not capable of operating in the sustained throughput regime of an abattoir and so can not routinely provide the information needed to support a processor at the full process scale.

In the aviation industry, X-Ray CT is used routinely for high throughput in-line screening of baggage passing from check-in to the hold of an aircraft. In this case, the Objective Measurement executed automatically and in real-time is the detection of explosive materials in baggage.

In this program, an aviation certified X-Ray CT scanner that produces high resolution 3D X-ray images at a continuous conveyor speed of 0.5m/s, Rapiscan Systems' RTT110, was delivered to Australia to conduct a program of scanning for the red meat industry to determine whether equivalency with the gold-standard medical X-ray CT could be achieved at full process speed over extended operating periods. The Australian red meat sector has uniquely benefitted by close technical access to this highly restricted technology through one of the top 2 global leading suppliers

Three separate sets of experimental work were conducted to analyse the performance of the scanner. The first limited study, in partnership with University of Sydney Veterinary Science lead by Prof Luciano Gonzalez, determined that RTT110 would be unlikely to meet the requirements for red meat industry Objective Measurement without some re-optimisation of the imaging system. The second study, a much larger study of 60 lamb carcasses, was conducted by the Murdoch University Meat Science team lead by Dr Graham Gardener. This study confirmed that RTT110 required improvements in image quality, although some aspects of the equivalency study (e.g. carcass volume measurement and carcass weight) showed similarity. The final limited scanning study was conducted by Rapiscan Systems at its factory in the UK following a major imaging chain upgrade programme comprising new X-ray sensors and a new image reconstruction engine. Image quality following this upgrade was improved significantly, to the point that it is very likely that subsequent R&D programs will demonstrate equivalency between RTT110 at full process line speed and medical CT used to scan single carcasses at a time.

Should equivalency be demonstrated in a subsequent R&D program, so allowing gold-standard Objective Measurement to be conducted in the abattoir at full process speed on a 24/7 operational basis, this will in principle provide the driver to full adoption of automation and the consequent improvements in yield, quality and consumer confidence in eating quality that will result. This could be achieved in the next stage of the program through the award of a product supply contract to Rapiscan Systems for specific food safe RTT products with deployment to the Teys Rockhampton beef boning room as part of the MLA supported prototype automated beef boning room development program as well as through scientific programs in meat and veterinary science in collaboration with Murdoch University and the University of Sydney.

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1 Background

Rapiscan Systems is an aviation security scanning business that supports the aviation industry (e.g. airport baggage screening, air cargo screening, port and border screening), critical infrastructure (e.g. buildings, power stations, hotels, transportation hubs), sporting stadia (e.g. Olympics, football and basketball) and military customers. Rapiscan Systems has three main manufacturing sites (one in the UK, one in the US and one in Malaysia) each supported by manufacturing, R&D, product and business development teams. Rapiscan Systems also maintains a separate Science and Technology (S&T) group to conduct strategic research and development that is at low technology readiness level (TRL 1 to 5) and that is some distance (1 to 5 years) from market. This program has been conducted by the Rapiscan Systems S&T team in collaboration with MLA.

MLA has established a major program of work in Objective Measurement leading to abattoir based DEXA scanning, calibrated by a medical X-Ray CT scanner, to drive automation programs in the abattoirs. Examples of this work abound with some published reports being

- V.MQT.0071 OM Value Proposition to Red Meat Stakeholders with 7 benefit scenarios
- P.PSH.0629 Lamb middle cutting system, ex-Post Review
- P.PSH.0629 ALC X-Ray Middle (with Primal) integrated automated lamb system
- A.TEC.0123 Beef and Lamb OCM with CT in situ further development

In all these programs, there is a consensus that medical grade three-dimensional X-Ray CT imaging provides a “gold standard” on which to build a program of accurate in-line objective measurement and automated carcass cutting in the abattoir production line setting.

However, a medical X-ray CT scanner operates at high power such that its X-ray tube gets very warm if used to scan a whole carcass or beef primal and will overheat if used to scan multiple carcasses or primals in succession. The practical utility of the technique is therefore limited at the full process scale where a carcass or primal should be scanned several times per minute over long shifts or even in some situations in a 24-hour continuous cycle.

Nonetheless, the case for using X-ray CT in the abattoirs is clear if a technological solution can be found to address the continuous operation requirement for the key 3D X-ray CT imaging component. The focus of this program was to determine whether standard aviation security style 3D X-ray CT scanners which are designed to operate with continuous throughput (of baggage) over 24 hours in automated, high reliability, installations, would be capable of satisfying the requirement for on-line, automatic, objective measurement in the abattoir.

If a transition could be made from an aviation style X-Ray CT scanner to the abattoir, then the red meat industry would benefit from decades of investment in the aviation security space with a scanning technology to deliver objective measurement data both to drive automation systems (so supporting reduced workforce costs) with overall yield increase (from more accurate primal cutting and improved de-boning) with more accurate valuation of carcasses (leading to fair prices to both producers and consumers). The result is an industry operating to higher quality standards with improved profitability in the global marketplace.

The primary goals for this program were to install a standard aviation CT scanner in Australia, use it to scan red meat product and determine whether the transition of this technology is in-principle suited to the abattoir application.

1.1 3D X-Ray Imaging in Aviation Security

Rapiscan Systems' customers use high speed 3D X-ray imaging for automatic detection of explosive materials that may be located in passenger baggage destined to travel in the hold of an aircraft. Regulator approved algorithms are used to clear baggage for onward transport. If a potential threat item is found, 3D image data is sent to an operator for review. Often the operator will be able to approve the bag for onward transport but, if the image inspector is not sure, the baggage will be manually searched to resolve any remaining risk item(s).

1.1.1 The Aviation Security Model

Figure 1 provides a simplified view of the chain of events (the centre blue squares in Figure 1) that occur from the time that a passenger starts to plan and book a trip to the time that they arrive at their destination airport. At each of these stages, a series of actions are taken, as described in the black text in Figure 1. These events are reasonably well understood by anyone that travels on a regular basis. Rapiscan Systems' main business is in the box labelled "Security Checkpoint".

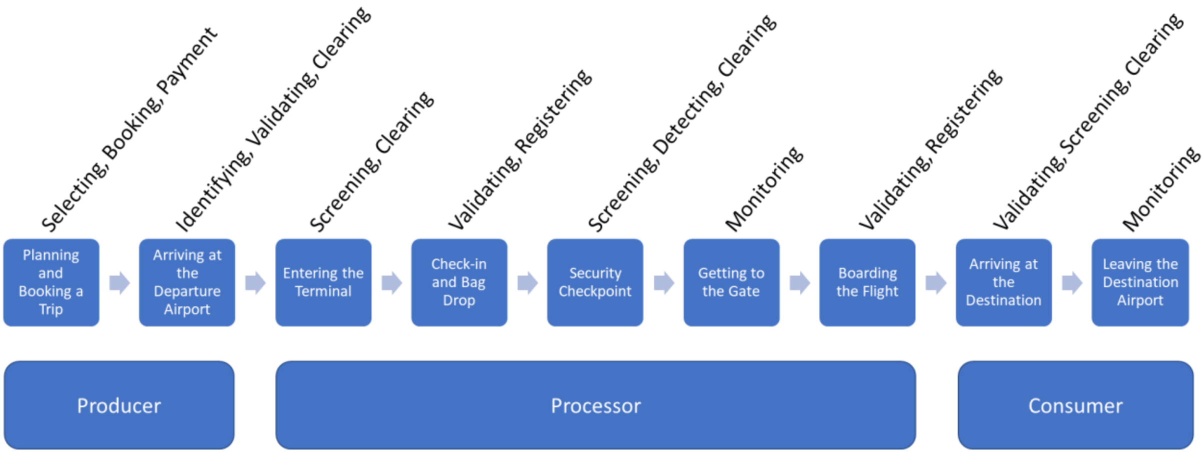

Figure 1: Model to show the chain of events as a passenger books a ticket through to departing on their flight.

At the lower part of Figure 1, a broad analogy is drawn to the red meat industry. Here a producer is somewhat like a passenger planning their trip and arriving at the airport. The Processor is analogous to a passenger moving through check-in, going through immigration and security and finally passing through the boarding gate. The Consumer is somewhat like the passenger arriving at their destination, excited by the experience that waits ahead of them.

1.1.2 Linking Aviation Security to the Meat Industry

Taking the analogy set out above a little further, Figure 2 describes the specific similarities between the aviation security model and the potential red meat industry model of the future in which automatic Objective Measurement occupies a similar role to the Security Checkpoint in the aviation sector.

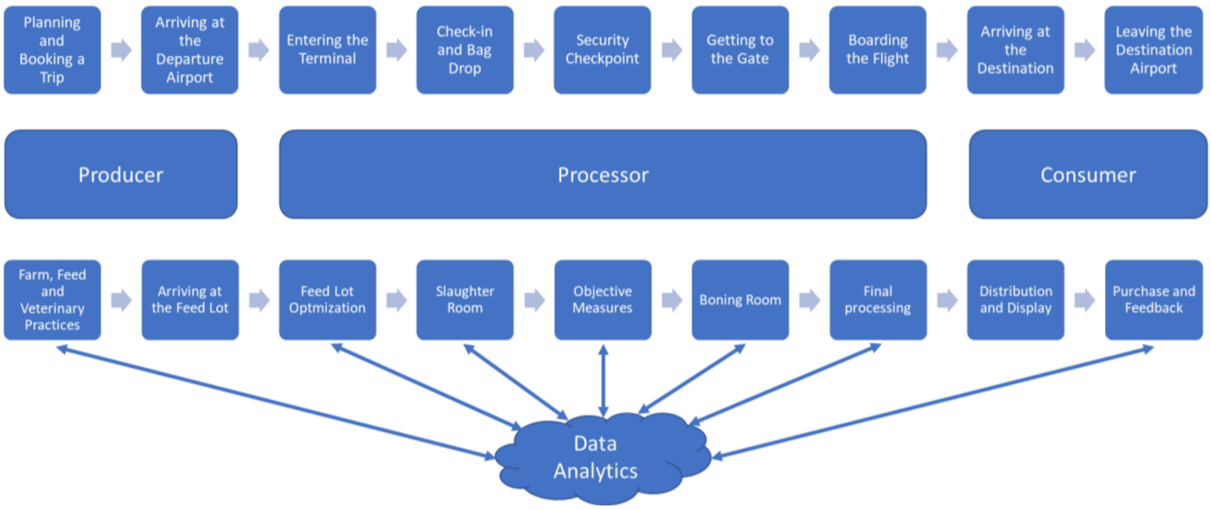

Figure 2: There are reasonable parallels between the chain of events in aviation security and those in the red meat industry.

In this case, through the use of data analytics, information from the Objective Measurement can be fed back to the abattoir to support production planning and provide data for specific processing of each carcass in order to maximise yield. The Objective Measurement data can also be fed back to the Producer to establish a fair price based on eating quality, lean meat yield and animal health metrics. The data can also be fed forward to the consumer to gain a fair price for a quality product, to minimise packaging and other quality control losses and to provide the consumer with supply chain data for each item that they purchase from their butcher or supermarket.

1.2 Why Use 3D X-Ray Imaging in the Red Meat Industry?

In the end, any investment by a Processor needs to lead to a financial return over a relatively short period through improved quality, improved productivity, improved yield and/or improved safety of staff and product. An independent comprehensive report (V.MQT.0071) sets out a clear justification for the use of Objective Measurement in the red meat industry while report A.TEC.0123 sets out a clear demonstration of the value of 3D X-ray imaging in delivering objective measurement data. Together, these reports, and the scientific data that they contain, provide the Processor justification for investment in a technological solution that can deliver real-time, high reliability, accurate, objective measurements. The final link in this chain is to evaluate whether a specific technology, in this case the transition of RTT110 stationary gantry CT from the aviation sector to the red meat sector, can provide the cost-benefit required for widespread adoption of Objective Measurement in each specific application area within the abattoir.

Any technology solution that is the subject of processor investment needs to start off as one or more programs that together deliver outcomes that result in impact. This process is described in Figure 3. In the case of Objective Measurement, several programs are needed to run in parallel to deliver successful outcomes. As an example, a 3D imaging program requires associated programs in automation, meat science, veterinary science, big data analytics and artificial intelligence to create a significant long-term impact on the red-meat industry. The outcomes from such programs will create value through image driven process optimisation (in which the 3D X-ray image data is used to deliver improvement in process automation, localised eating quality within each muscle, lean meat yield and an analysis of animal health), through improvement in animal health and genetics (by feeding back data on Objective Measurement on an animal specific basis) and in overall customer satisfaction (by ensuring the correct quality of meat is supplied at a fair price). At this point, the Processor and Producer will each derive an improved return on investment, and consequent improvement in profitability, as required to drive the innovation process in the first place.

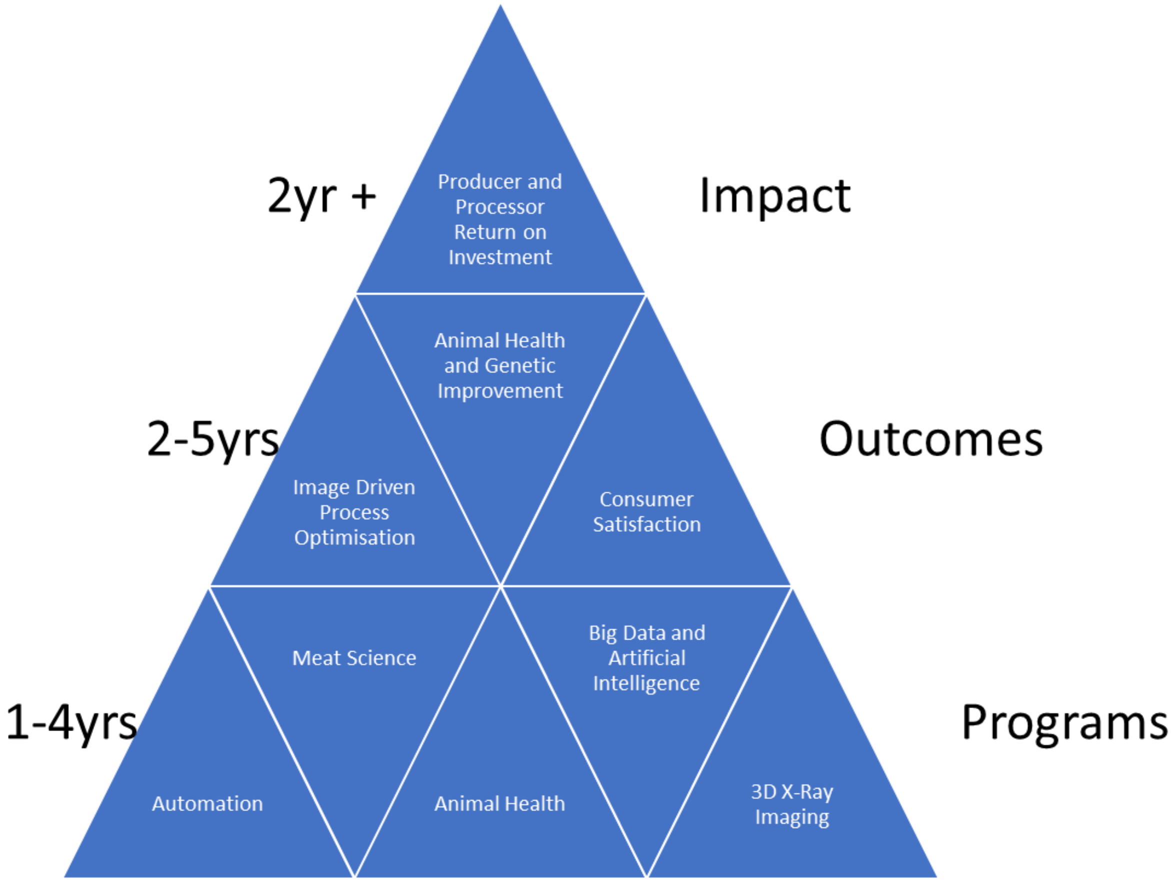

Figure 3: The relationship between programs, outcomes and impact for a research program in Objective Measurement.

1.3 Program Aims

In this program, the key aim was to explore the role that 3D X-ray imaging can play in supporting programs in Big Data and Artificial Intelligence, in Veterinary and Meat Science and in Automation to deliver the outcomes required by both Producers and Processors in improving overall efficiency and profitability of the red meat industry.

The specific goals were to introduce Rapiscan Systems' RTT110 3D X-ray scanner technology from the aviation industry into the red meat industry, to conduct scanning of red meat product and to evaluate its potential for supporting complimentary programs in automation as well as meat and veterinary science.

Having invested heavily in its core Real-Time Tomography (RTT) technology for the aviation sector, Rapiscan Systems is interested to see whether the red meat industry could be a second market for its technology. By working and co-investing with MLA, Rapiscan Systems has been able to gain significant insight into the industry as a whole and to meet leading industry players from across the sector. This has also led to establishment of a major Rapiscan Systems R&D centre in Australia with other Australian Government customers outside the core aviation sector.

2 Project objectives

2.1 Objective 1 – System Build

Build a 1000mmm x 650mm tunnel size RTT110 scanner with single energy detectors and scanning speed of 0.5m/s.

2.2 Objective 2 – Installation in a Red Meat Facility

Deliver this scanner to a meat industry facility operating site of MLA's request and install it for offline use in a clean room at such facility by end June 2018.

2.3 Objective 3 – Data Collection and Analysis

Once the scanner is installed, the image data shall be collected and used for system objectives of the Project by a team of Rapiscan's engineers to be located in Sydney.

2.4 Objective 4 – Program Collaborators

The data shall also be provided to MLA's collaborators on the program if agreed to under Project Variations.

3 Methodology

3.1 Aviation 3D X-Ray Imaging System – RTT110

The RTT110 was designed by Rapiscan Systems from the ground up as a dedicated X-ray CT scanner for aviation security, rather than starting by adapting medical X-ray CT scanning technology for a new application. The result was a unique approach to the problem in which a static gantry CT was developed to eliminate the speed versus heat trade-off that exists in medical CT scanners. Rapiscan Systems calls this static gantry CT approach Real-Time Tomography (RTT).

The RTT110, as shown in Figure 4, has a 110cm diameter image reconstruction circle (hence the name RTT110) which is large enough to fit the majority of beef primals and whole lamb carcasses. The conveyor width is 1000mm with a maximum tunnel height of around 650mm. A conveyor belt passes through the imaging system to convey baggage (or primals and carcasses) from input to output at a continuous scanning speed of 0.5m/s.

The system is fully self-contained as a radiation safe unit for baggage throughput up to 1800 bags per hour. The X-ray beam is generated with a tube voltage of 160kV.

Figure 4: Photograph of the Rapiscan Systems RTT110 scanner designed for airport baggage screening applications.

Image data is reconstructed by a computer system inside the RTT110 in real-time with a reconstructed voxel dimension of around 1mm x 1mm x 1mm. Image data is available on the inspection screen almost immediately with imaging tools provided for full inspection of the 3D X-ray image data.

In aviation applications, an automatic explosives threat detection algorithm executes on the freshly reconstructed X-ray CT slice data so that a threat assessment of the bag is completed very soon after the trailing edge of the bag leaves the X-ray scanning region and well before the bag emerges from the end of the scanner onto the subsequent conveyor. An example of the result of a scan with automatic explosives detection is shown in Figure 5. Here three types of explosive material have been detected automatically (bulk, sheet and home made). This image has been presented as a 3D image using the RTT's GPU based volume rendering engine and dedicated imaging workstation.

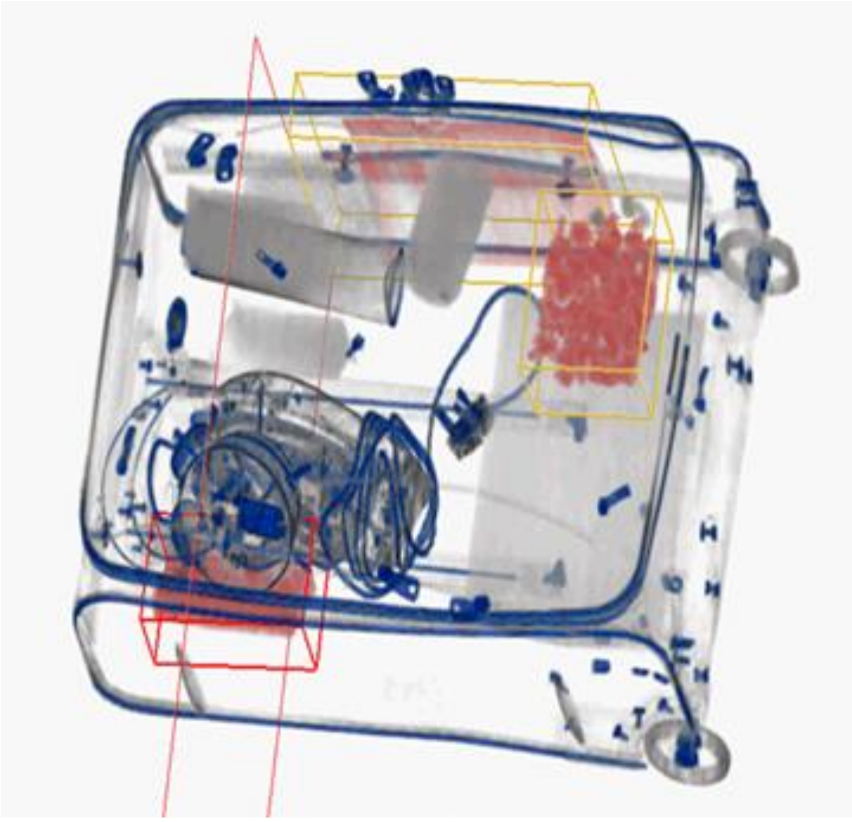

Figure 5: Example aviation image from RTT110 showing a bag with simulated bulk, sheet and homemade explosive materials. These have been highlighted in red as a result of detection using a regulator approved explosives detection algorithm.

A simple graphic of how the RTT110 could be applied in the red meat industry is shown in Figure 6 (image courtesy of MLA). Here, the beef primal or lamb carcass is fed into the scanning system using the built-in conveyor from one end of the scanner (the left end in Figure 6). As the primal or carcass moves through the scanner, the slice data is reconstructed and passed to an Objective Measurement algorithm which executes on the X-ray image data in real-time. The algorithm analyses the slice data, recognises the type of primal or carcass being scanned, identifies muscle groups and then calculates Objective Measurements such as lean meat yield, eating quality, fat layer thickness, location of bones etc and so generates output data relevant to the producer, processor and consumer as well as for following automation systems where precise knowledge of the position of muscle groups and bones is critical.

Figure 6: The concept behind the use of 3D X-ray scanning in the red meat industry.

Under this contract, an RTT110 system was manufactured by the Rapiscan Systems' factory team in the UK and was shipped to Australia in the second quarter of 2018. This system was built to the standard aviation industry specification. At the same time, a team of software and algorithm engineers was recruited in Sydney, NSW, to start the complex process of developing Objective Measurement algorithms on the real-time RTT110 image data.

The algorithm development process always starts with deep understanding of the quality of the data produced by the scanner in the context of the problem set that needs to be addressed. In this case the initial problem set in the red meat industry abattoir setting can be broadly defined as:

- Calculation of lean meat yield
- Calculation of eating quality
- Assessment of animal heath
- Accurate measurement of 3D structure of the carcass

Each of these top-level measurements leads to a series of dependent assessments that include:

- Carcass valuation
- Subsequent processing and de-boning strategies
- Automation systems optimisation on a per carcass basis
- Packaging strategy
- Consumer satisfaction and product quality metrics

The initial approach to algorithm development by the Rapiscan Systems team focussed on 3D image segmentation into fat, lean and bone. This is the basic driver for calculation of lean meat yield and accurate measurement of 3D carcass structure. These are key to delivering Processor return on investment through (1) paying a fair price for each carcass based on lean meat yield, and (2) process optimisation and automation through accurate understanding of carcass structure.

Accurate fat, lean and bone segmentation requires deep understanding of CT image quality and image reconstruction artefact and this is where the algorithm development process starts. A considerable part of the Rapiscan Systems algorithm development program was focussed on reducing image reconstruction artefact and improving reconstructed signal-to-noise ratio to get to the point where an accurate fat-lean-bone segmentation could be achieved.

A next step is to look at automatic measurement of inter- and intra-muscular fat distribution and content since this drives calculation of eating quality with outcome in consumer satisfaction and product yield and quality.

A further step is to detect possible health defects such as tumours, cysts, over- or under-sized anatomic features, low bone density, metal inclusions, other foreign objects and so on. This affects carcass valuation as well as consumer confidence in the product produced by the industry.

This work requires a multi-disciplinary team of scientists, engineers and industry experts to ensure that all aspects of the system design are addressed, continuously identifying and eliminating the weakest link in the chain to improve overall system performance.

3.2 Planned Abattoir Data Collection

Key to achieving a successful algorithm is the availability of lots of relevant image data. Therefore, Rapiscan Systems developed a proposal (Figure 7) to conduct scanning at the JBS Brooklyn plant in Melbourne, VIC. MLA had suggested this plant since there was already a MLA sponsored medical CT scanner at that site and there was, in principle, space to put the RTT110 adjacent to it within the cold room of the abattoir.

A great advantage of this proposal was the ability to conduct scanning on both the aviation and medical CT scanners on the same items to generate two sets of data that could both have algorithms developed for the same Objective Measurements. This would establish the basis of equivalency, or otherwise, between the gold standard medical CT and the aviation based RTT110.

Another advantage of the JBS Brooklyn site was that JBS process both beef and lamb at that abattoir so providing a perfect location for generating the data needed to fuel an algorithm development team.

A final advantage was that the JBS Brooklyn plant was near to the Melbourne CBD so making access to the plant straightforward to Rapiscan Systems personnel.

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Rapiscan systems
An OSI Systems Company

JBS Brooklyn
RTT110 Installation and Scanning Program

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Date	22nd June 2018	Document Owner	Ed Morton

Form R-0438-2

Figure 7: Front cover from our research proposal setting out a program in Lamb and Beef Primal scanning an JBS Brooklyn.

3.2.1 Data Collection

The Rapiscan Systems research proposal called for an intensive scanning period of 4 weeks from August 2018 to September 2018. During this period, it was planned to scan 4 carcasses per hour first on RTT110 then on the medical CT scanner. Over an 8-hour day, 5 days per week over 4 weeks this equated to 640 scanned carcass datasets from RTT110 and a further 640 scanned carcass datasets from the medical CT system.

The objective was to scan a variety of lamb carcasses from light weight to heavy weight with varying numbers of ribs. Where available, ancillary data such as weight and animal ID was planned to be merged with the X-ray image data into a full database of images.

As well as lamb data, a series of beef primals were to be scanned to build out a representative dataset for major primals of interest.

3.2.2 Algorithm Development

A small team of algorithm and software engineers plus a data scientist to work at the JBS plant and perform the scanning activity was planned. The software engineering task was to construct the database to store the image data plus develop the infrastructure needed to visualise the image data and execute algorithms. The algorithm engineering task was to analyse the images in order to generate Objective Measurement data in order to determine how effective RTT110 would be at analysing red meat as opposed to baggage.

3.2.3 System Equivalency

The data collected from the medical CT and RTT110 systems would then be used to conduct an equivalency study between the two units to establish:

1) Relative accuracy of each system for determining the location and presence of bone features with the carcass (e.g. end of a rib)
2) Relative accuracy of each system for determining lean meat yield
3) Relative accuracy of each system for determining eating quality

Where a significant difference was found between the performance of the RTT110 to Medical CT system, the image quality parameters that drive that difference would be investigated. This information would be used to drive an imaging system upgrade program for RTT110 to enable similar performance for objective measurement between the two systems to be achieved.

Ideally, the RTT110 system would be re-installed at JBS Brooklyn following the system upgrade to verify whether further equivalency had been obtained.

3.3 Automatic Analysis Software

The Sydney based software team has been responsible for developing the software platform that is used for delivering Objective Measurement algorithms. The overall architecture of the algorithm platform is shown in Figure 8.

Image data from the scanner arrives in real-time through the imaging pipeline into the main Algorithm Feature. The Algorithm Feature subscribes to data published by the image reconstruction engine and publishes data that is subscribed to by the user interface.

Once the Algorithm Engine has received a new set of data, it passes down to a Deep Learning wrapper which in turn manages the execution of algorithms either in the TensorFlow environment using a Python interface or in the DLib environment using a C++ interface.

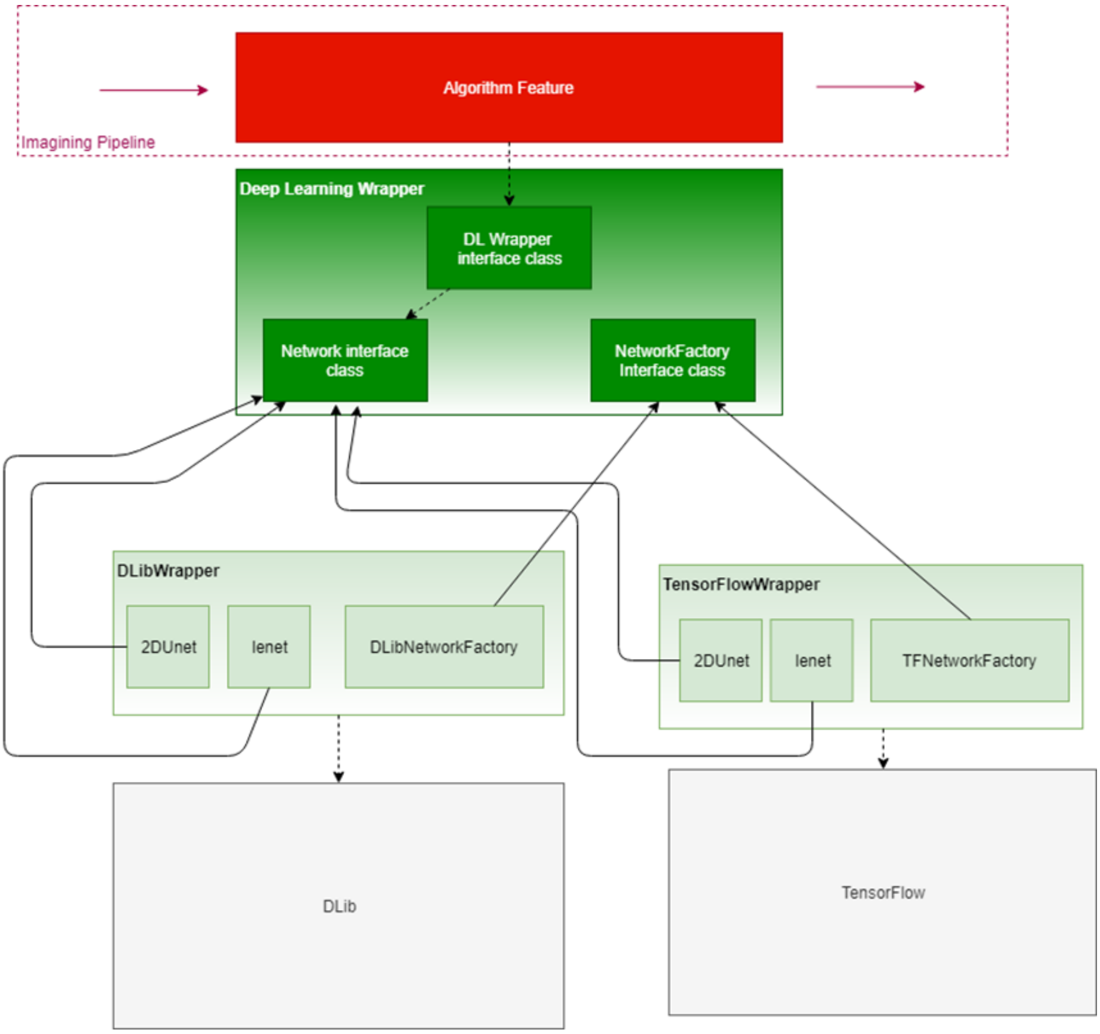


Figure 8: Software infrastructure developed to allow multiple algorithms for the red meat industry to execute simultaneously, and in real-time, on RTT110 3D X-ray image data.

During analysis of run-time speed, it was found that the DLib compiled C++ environment executes significantly more quickly than the interpreted TensorFlow environment and so is better suited to the high data bandwidth encountered with RTT110 image data (one image slice of 950 x 680 pixels every 2ms, or every 1mm of conveyor movement, with ~ 600 GByte/sec maximum data rate).

Artificial intelligence algorithms based on deep layer convolutional neural networks have been developed for fat-lean-bone segmentation by the Rapiscan Systems Sydney team. An example network based on the 2D-UNET approach is shown diagrammatically in Figure 9 and this has proven to be both fast and efficient at segmenting RTT110 image data, albeit not at full scan speed. The objective of this work was to determine inter-muscular fat to calculate Lean Meat Yield estimates. A separate training process can, in-principle, be adopted for determination of intra-muscular fat distribution, a key contributor to marble score and related eating quality indices. Insufficient data was available to attempt this during the program during this program.

To understand the code execution time with a view to making the code execute in real-time, Figure 10 provides a graphical view of how the CPU and GPU work together to execute the DLib 2D-UNET code. At the CPU side, a series of jobs are sent to the GPU in rapid succession over a time period of around 0.4ms per slice. The GPU then executes these instructions one after the other and eventually returns a result. In the meantime, the CPU remains idle waiting for the next slice to appear. If it takes more than 1.5ms for the GPU to complete its tasks, then the system is no longer capable of operating in real time unless multiple GPU cards execute in parallel. This would be both complex to integrate and expensive to deploy. Currently, it takes around 8ms per slice to complete the analysis which is 6.5ms too slow to operate in real time. Alternatively, the conveyor belt could be slowed down by a factor of five to run at 100mm/s instead of the required 500mm/s. This may be almost sufficient for red meat industry applications in which case the use of deep learning approaches may become suited to the Objective Measurement application.

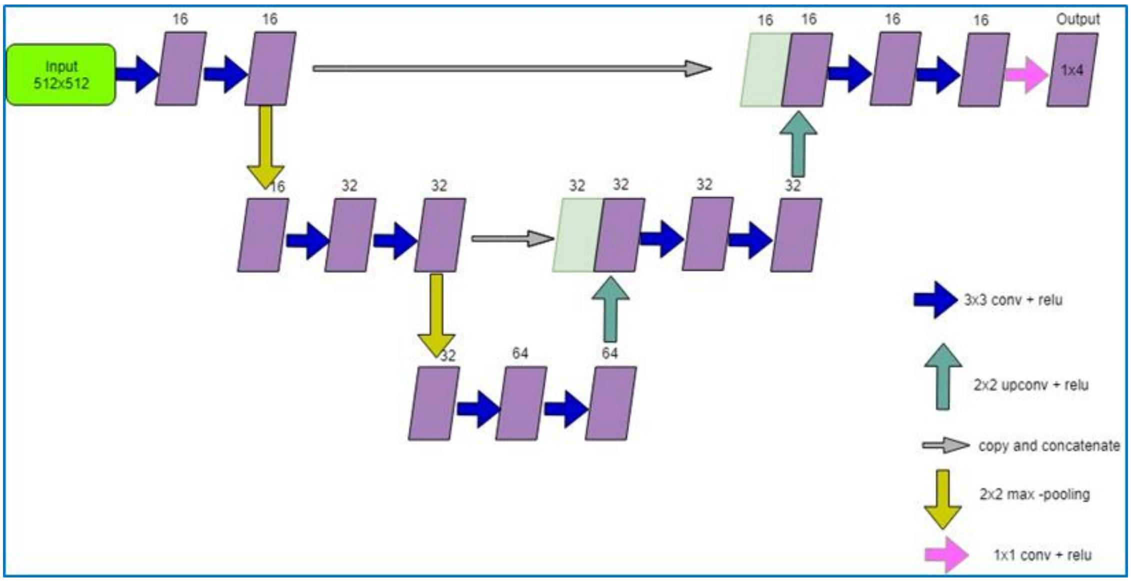


Figure 9: Example 2D-UNET neural network that was developed for automatic segmentation of bone, lean and fat for red meat 3D X-ray image data.

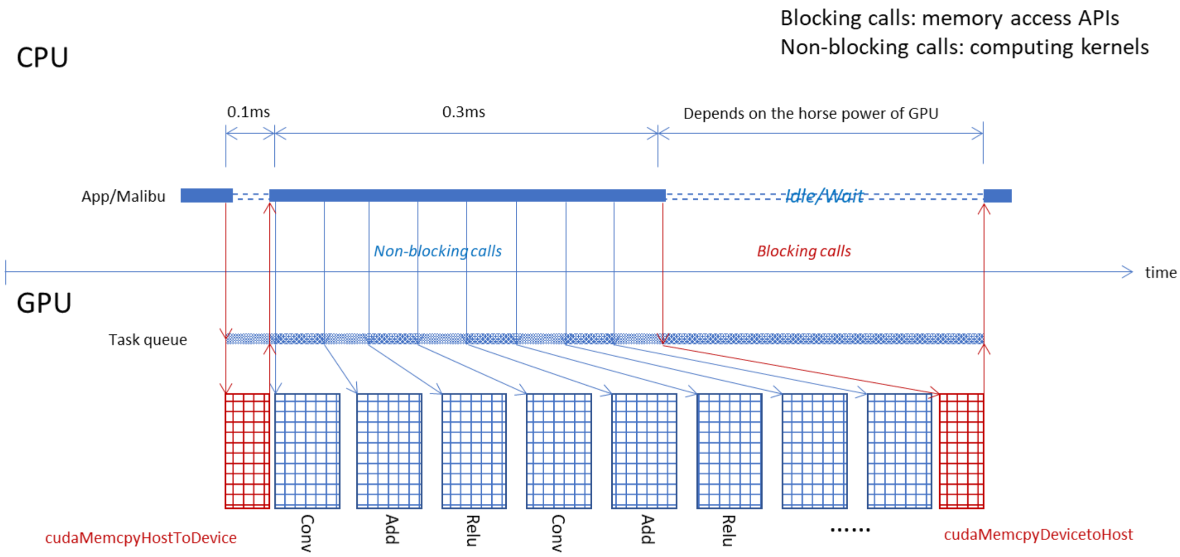


Figure 10: Code profiling for DLib 2D-UNET segmentation code.

3.4 Image Reconstruction Algorithms

In order to improve image quality, a substantial program of work has been conducted in the area of image reconstruction from projections. The basic premise of this work is that the raw projection data acquired by firing X-ray beams from a multiplicity of source points to a multiplicity of X-ray detector elements while the conveyor belt is moving continuously can be reconstructed into a three-dimensional volume by (1) normalising the projections to remove effects of source brightness and detector responsivity variations, (2) multiplying individual values by geometrical weighting factors, one for each source-detector combination, (3) applying de-blurring filters in the Fourier domain, (4) backprojecting the filtered data and (5) creating the output image. This process is summarised in more detail in Figure 11.

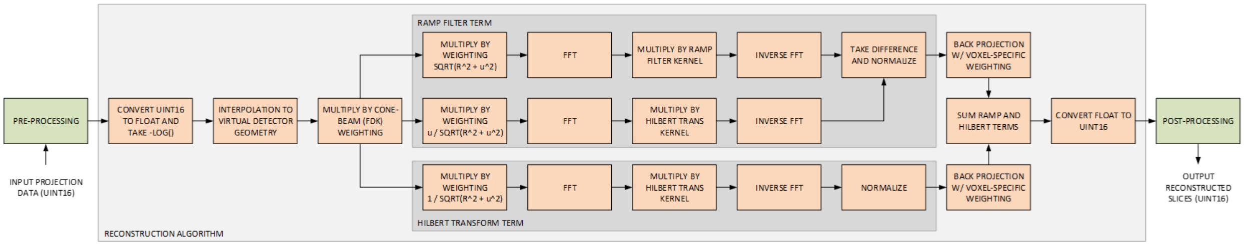


Figure 11: Block diagram of the image reconstruction code developed during this program.

As well as developing the mathematics behind the reconstruction algorithm to solve for the specific geometry that is embodied in the RTT110 scanner and testing this algorithm in an off-line code to validate its performance on simulated data, a full implementation of the algorithm was made to execute in real-time with a 500mm/s conveyor speed. This is a very efficient implementation that has been made on a single mid-range (and therefore moderate cost) GPU card. With moving data from the CPU to the GPU and back again, around 20% spare GPU capacity is available for future expansion, such as to dual- or multi-energy image reconstruction.

4 Results

4.1 RTT110 Shipping and Installation

4.1.1 Installation at Scott Automation, Tullamarine.

The original shipping destination for the RTT110 unit from the Rapiscan Systems factory in the UK was JBS Brooklyn, Melbourne, VIC. However, once landed in Australia, MLA and JBS determined that the trial should not go ahead. Two main factors lay behind this decision:

1. The medical CT scanner at the Brooklyn plant had failed and MLA did not have a plan to repair this back to operational state. This meant that the equivalency study could not be performed to show the efficacy, or otherwise, of the RTT110 for red meat applications.
2. The JBS team did not feel comfortable with an airport scanner company working in their facility and attempting a large scale red meat industry scanning trial with an untested scanning system, with no medical CT system for equivalency in an experimental area that the JBS operations team wished to re-allocate back to operational status to deliver more urgent value adding activities.

For these reasons, MLA and JBS asked Rapiscan Systems to divert the RTT110 unit (now in storage at the port in Melbourne) to another location.

Very kindly, Scott Automation offered to house the RTT110 unit on a temporary basis at their facility in Tullamarine, Melbourne, VIC. The unit was installed there late June 2018 in a standalone configuration (see Figure 12).

Figure 12: Photograph of the RTT110 system installed at the Scott Automation facility in Tullamarine, VIC.

4.1.2 Installation at Melbourne Mail Gateway Facility

Under the terms of the Rapiscan Systems contract with MLA, for 6 months of the year, the RTT110 unit in the MLA project could be used for Rapiscan Systems purposes. Therefore, in June 2019, the MLA RTT110 unit was re-located to the Melbourne Mail Gateway Facility to conduct a scanning trial with the Department of Agriculture on automatic detection of inbound biosecurity risk goods in the mail pathway. For more details of this program, see section 6.3 of this report.

4.2 Initial scanning at Tullamarine

While installed at Tullamarine, an initial set of scans were conducted by collaborators from the Department of Veterinary Science at the University of Sydney: Prof. Luciano Gonzales and the Department's Rapiscan Systems sponsored PhD researcher Cassius Coombes. The focus of this University research was predicting meat yield and quality in Australian beef. Their initial work was presented at the annual MLA Students Conference held in November 2018.

While working with the RTT110 unit in Tullamarine, The University team scanned some packaged beef from a supermarket including the sample shown in Figure 13. Here, two separate slices are shown which clearly show bone as distinct from tissue, although resolving fat from lean is less easy.

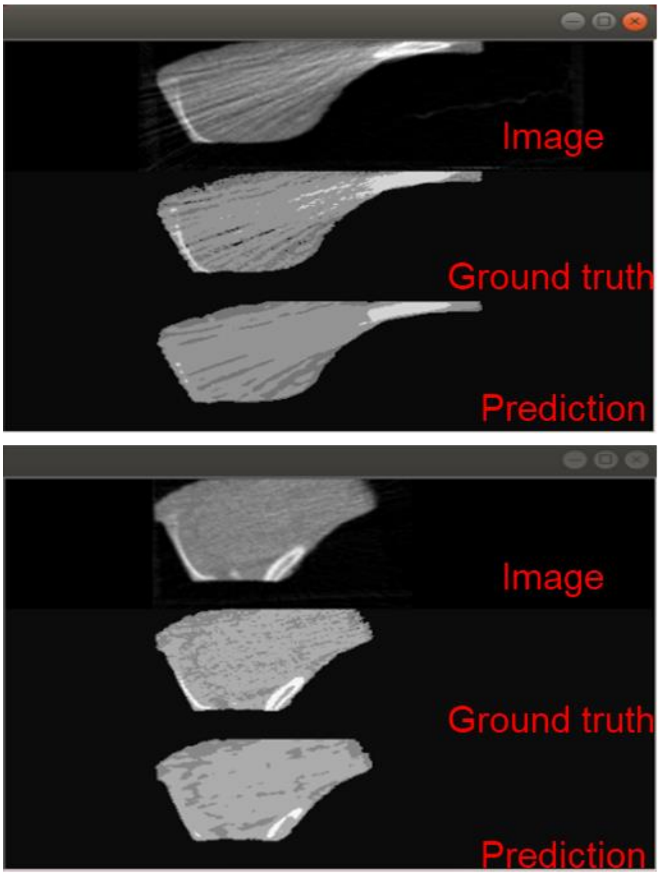


Figure 13: Initial set of beef ribs scanned using RTT110 at Tullamarine. An automatic algorithm has been run on the data to segment out bone, lean and fat. Two different slices through the primal are shown in the figure.

For each set of data, the top image in the set of three in Figure 13 is the raw image from the RTT110 scanner. The middle image shows the data as marked up by University of Sydney's Cassius Coombes into bone, lean and fat regions while the bottom image shows the result of an automatic segmentation of the image using a 2D-UNET convolutional neural network as described in section 3.3 above. There is reasonable, although not perfect, correlation between the expert annotated and computer analysed image data. This initial result suggests that the RTT110 is almost good enough to generate red meat industry Objective Measurement data in its standard aviation configuration.

4.3 RTT110 Data Collection with Murdoch University

In mid-2018, Rapiscan Systems and Murdoch University started to plan a three-way research program with MLA to develop a program on Objective Measurement and X-ray CT scanning. By early 2019, this proposal was at an advanced state of preparation. Under this program Murdoch University would undertake the necessary meat science to establish equivalency (or otherwise) between RTT110 and medical CT scanning, so directing Rapiscan Systems on how best to optimise the RTT110 scanner to deliver value to the red meat industry. The proposal was presented to the MDC board, but the proposed additional investment was not approved with a recommendation to provide, in addition to the detailed scientific case presented by Murdoch University, a detailed business case from Rapiscan Systems backed by results from existing project investments.

Nonetheless, in February 2019, Dr. Graham Gardener and his team from Murdoch University conducted a scanning sequence of 60 lambs as part of the DEXA unit calibration at JBS Brooklyn. In this study, the lamb carcasses were cut into three parts (between the 4th/5th rib and in the lumbar region) resulting in a total of 180 scans. The full set of lamb parts were scanned both on the RTT110 at Tullamarine and on the University of Melbourne Veterinary School medical X-Ray CT scanner. The Murdoch University team kindly made the medical X-ray CT scans available for Rapiscan to do some initial image comparison work, on the understanding that Rapiscan Systems is an aviation specialist, not a red meat industry specialist.

Figure 14 provides some 3D rendered images of three parts of one of the 60 lamb data set acquired using the RTT110 scanner. Given the relatively high spatial resolution of the RTT110 scans, the surface renderings provide good definition of carcass volume.

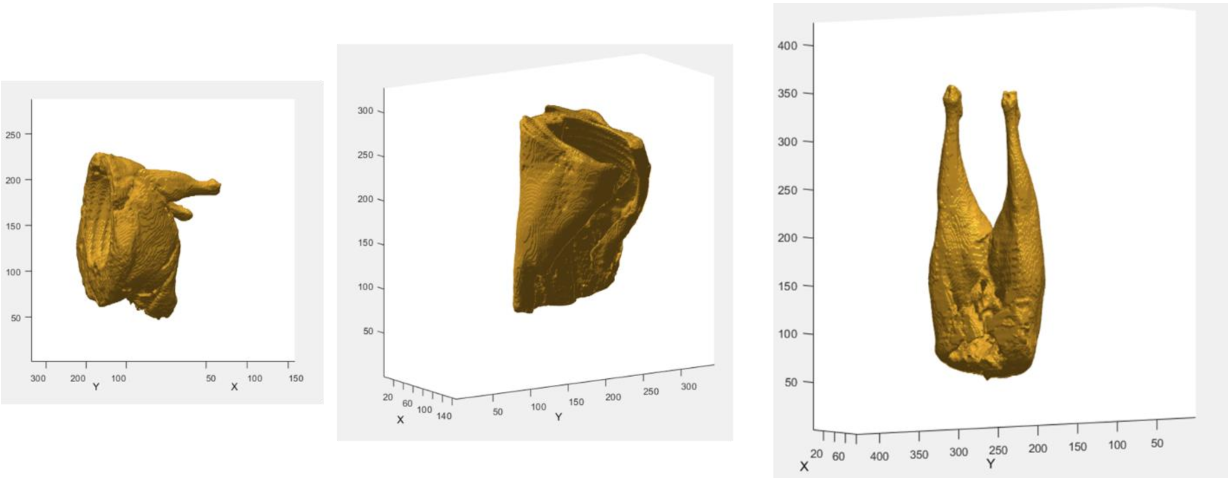


Figure 14: 3D surface rendered images of fore, mid and hind quarters of a lamb that were scanned on RTT110 by the Murdoch University team.

The raw data that goes into these volume images comprises a stack of slices which together form the 3D volume image. Figure 15 provides three slice images through the neck and thorax of a lamb labelled using medical notation (coronal, sagittal and axial views).

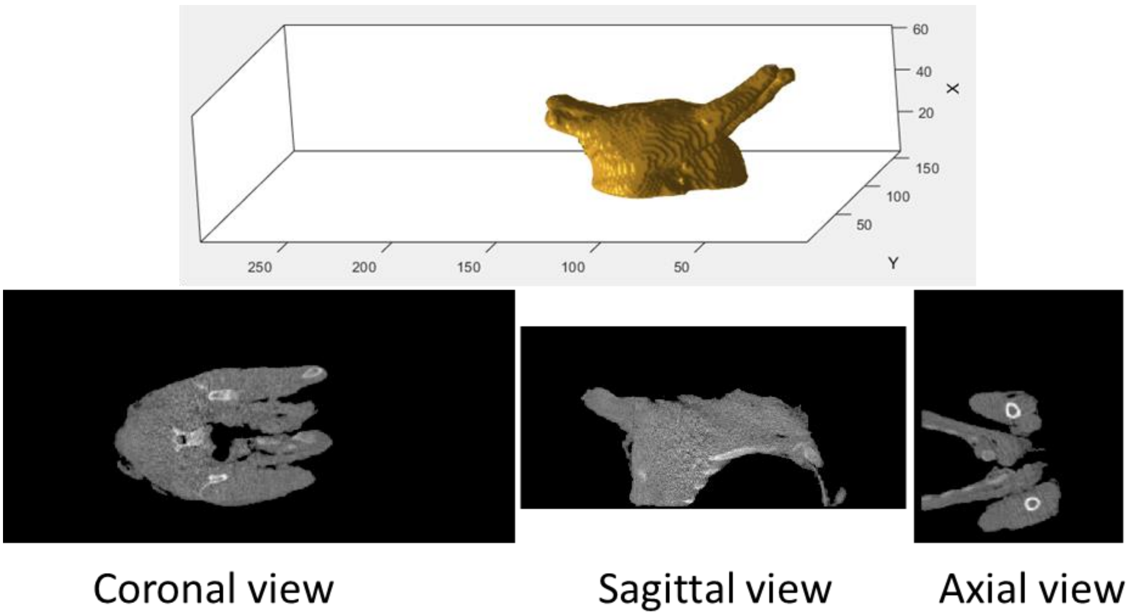


Figure 15: Example slice views through the neck and thorax section of a lamb carcass showing the presence of bone (white). lean (lighter grey) and fat (darker grey) tissues.

Again, there is good definition between bone and tissue but less good definition between fat and lean tissue. That said, there is enough tissue contrast to do a basic carcass segmentation into bone, lean and fat. Such a segmented image is shown in Figure 16. In the upper part of this figure, the raw image data is shown. In the lower part of the figure, the segmented image (segmented using the 2D-UNET deep learning-based algorithm) is shown in which regions of lean and fat have been correctly identified. In the shoulder muscle area, there is not an accurate match between the anatomy and the segmented image data, showing the segmentation is at the edge of its performance boundary.

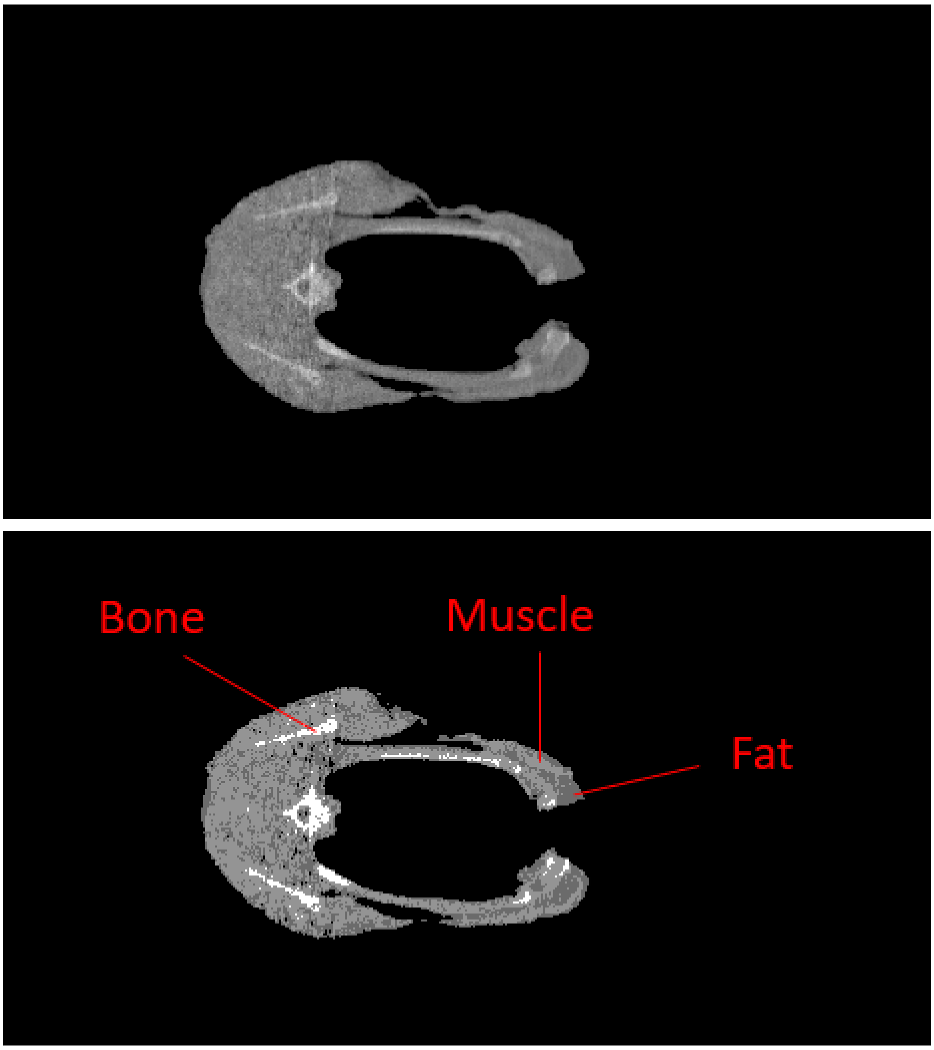


Figure 16: Single slice view of the end of a lamb shoulder and rib section showing bone, lean (muscle) and fat regions.

Having segmented into fat, lean and bone, it is then possible to assign nominal densities to each material and so derive a total mass contained in each slice. By summing data from adjacent slices, it is therefore possible to calculate mass of the whole carcass. Using a literature value for muscle of 1.05g/cm3 and for bone of 1.85 g/cm3, carcass weights were calculated for all 60 lambs in the Murdoch University data set as shown in Figure 17. As expected, there is a distribution of carcass weights from small (~10kg) to large (~40kg). The actual carcass weights are not available for comparison but the general results look reasonable.

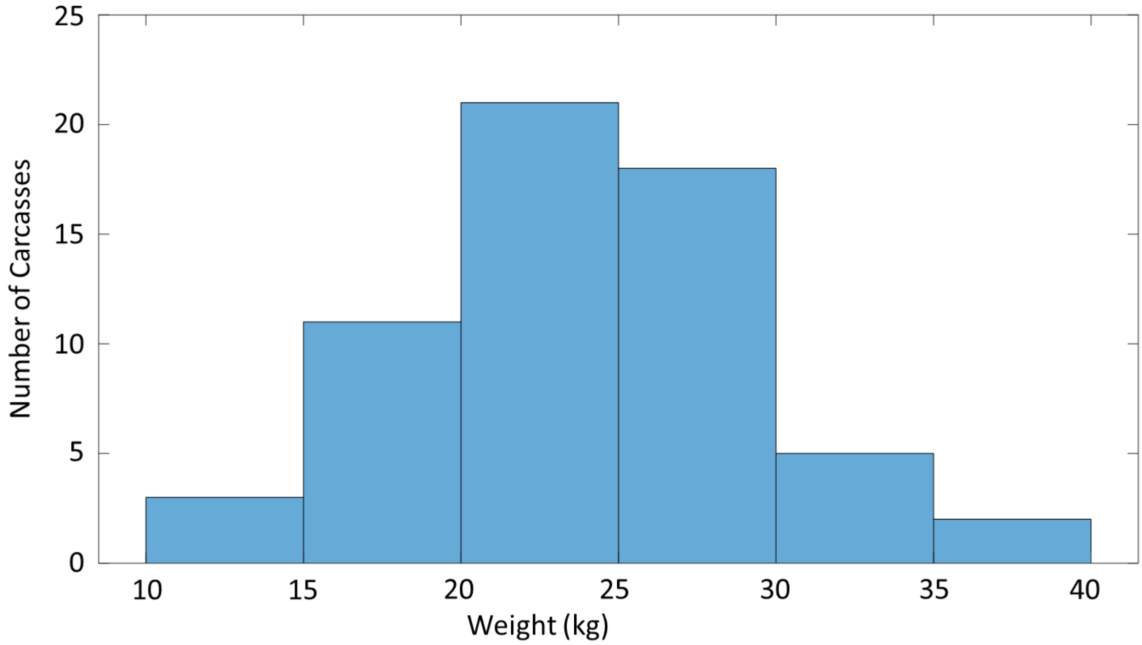


Figure 17: Automated analysis using a deep learning (AI) method for calculating weight of each carcass in the Murdoch University set of 60 lambs.

X-ray CT slices from the medical CT scanner were also analysed. Because the conveyor is removed automatically from the RTT110 images, it was necessary to develop an automatic algorithm to remove the patient bed from the medical CT images into order to repeat the weight calculation for comparison purposes.

An example of medical image data for three parts of a lamb carcass are shown in Figure 18. Here, an automatic algorithm developed by the Rapiscan Systems team has identified the upper part of the patient bed by highlighting this in a red colour. In the subsequent analysis, all pixels from the red line and below are set to air values so that they do not take any further part in the analysis.

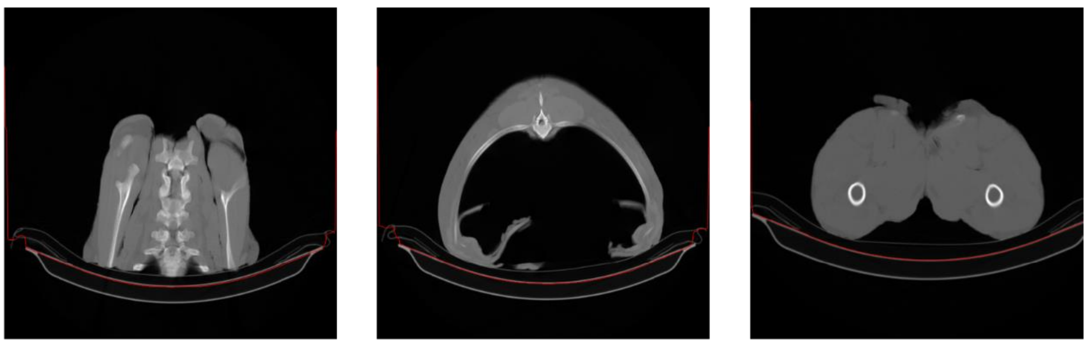


Figure 18: Medical CT scanner data from one of the 60 lambs in the Murdoch University data set showing the curved bed on which samples sit.

Once the bed has been removed from the image data, the neural network technique was used to segment the image into bone, fat and lean. The bone regions were filled in with bone material in order to get a more realistic carcass weight, since bone density is commonly specified for the entire bone volume, not just through the dense part of the bone volume. The stages used to prepare the medical X-ray CT lamb dataset for analysis is shown in Figure 19.

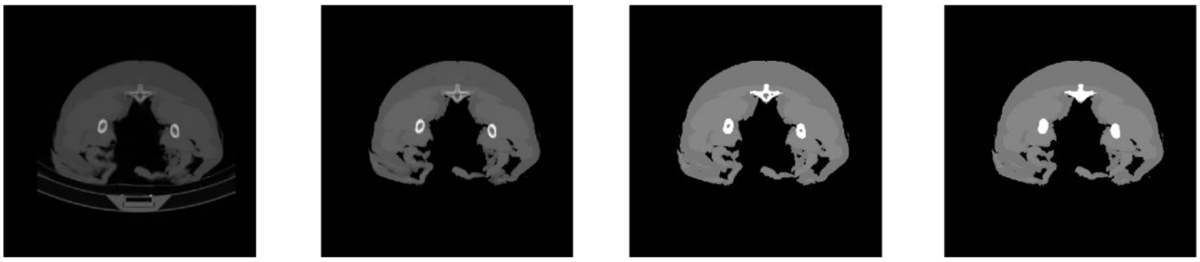


Figure 19: Process steps from raw medical CT image (left) to bed removal (2nd left) to fat-lean-bone segmentation (2nd right) to final segmented image with bone filling (right).

Once the full set of image data had been processed according to the steps shown in Figure 19, a series of analysis routines were written to calculate basic properties for the carcasses from both the RTT110 data set and for the Medical CT data. Some results are presented in Figure 20.

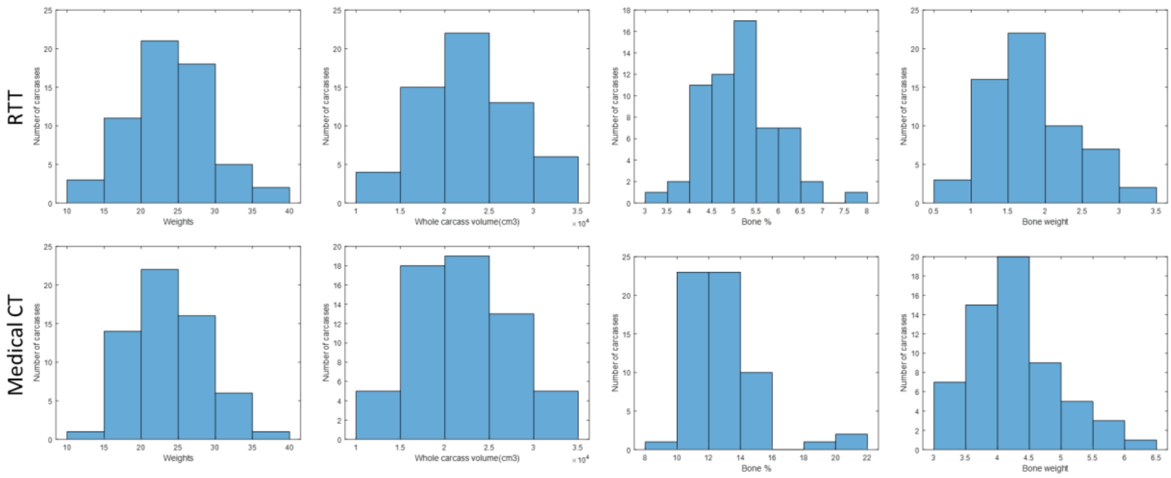


Figure 20: Comparison between analysis of RTT110 scanned image data (top row) and medical CT scanned image data (bottom row) for carcass weight (left), carcass volume (2nd left), bone percentage (2nd right) and bone weight (right).

In some respects, the results from RTT110 and Medical CT appear similar. For example, the distribution of carcass weights (see left most graphs) are quite similar between the two data sets, although not identical. Similarly, there is reasonable agreement, although not equivalency, in the whole carcass volume measurement (second left set of data).

However, in calculated bone percentage (second right set of data) and bone weight (right most graphs) there are substantial differences between the two sets of data.

As a further example, calculated lean meat yield between the RTT110 and medical CT scan data show significant differences (Figure 21). The RTT110 consistently, and substantially, underestimates lean meat yield compared to the medical CT scanner.

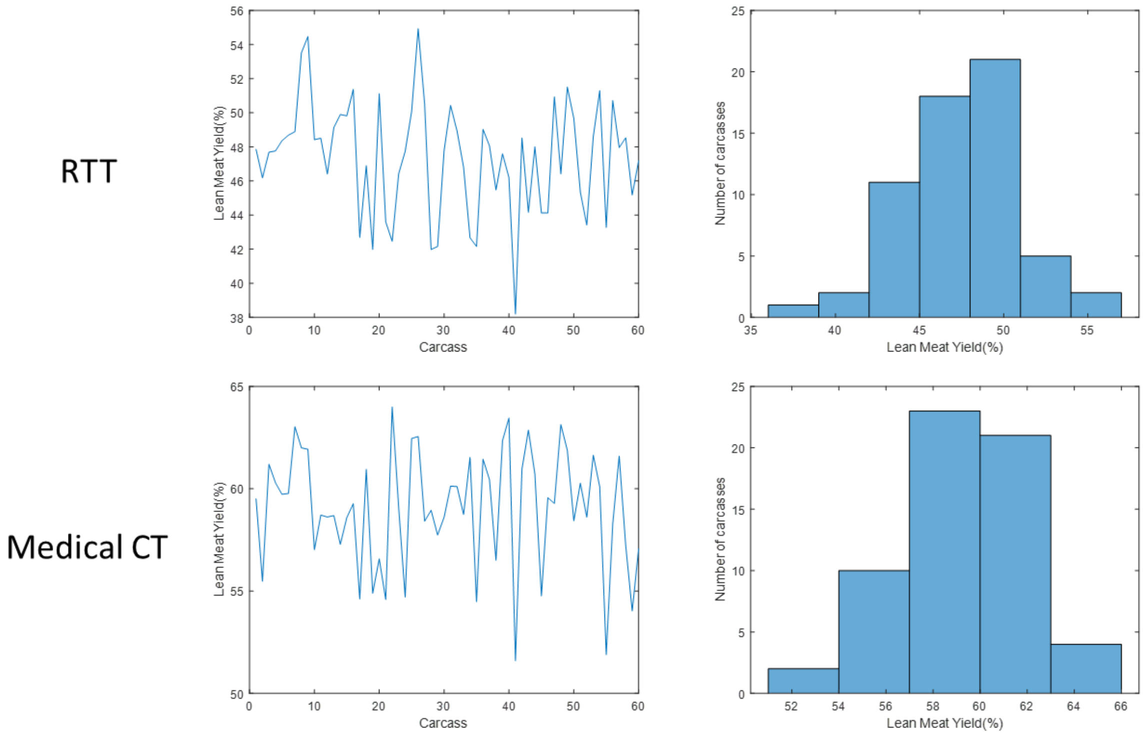


Figure 21: Calculated lean meat yield for the 60-lamb set obtained using RTT110 image data (upper row) and Medical CT image data (lower row).

Although Rapiscan Systems is not expert at meat science, we believe that the differences in the bone percentage, bone weight and lean meat yield come from imaging artefact which is inherent in all X-ray CT scanners. Beam hardening describes the combination of the broad band energy emission from the X-ray source (from zero up to maximum tube energy, 160keV for RTT110 and typically 120keV to 140keV for a medical X-ray CT scanner) with the variation in mass attenuation coefficient of materials which also varies rapidly with energy, especially at these relatively low energy X-ray energies. The result is a non-linear response recorded by the detector (which also has a variable sensitivity with energy) which results in incorrect density being calculated in the final image data. Medical CT scanners tend to operate with heavy beam filtration to minimise this effect which is one reason that they have to operate with very high X-ray power levels. In RTT110, the optimisation is to run with relatively light filtration to allow much lower X-ray powers but with an increased beam hardening effect.

Further, the RTT110 with its relatively low X-ray beam power also produces streak artefacts caused by X-ray photon starvation. These photon starvation artefacts can be seen clearly in the upper right image of Figure 23, as an example.

The combination of beam hardening effects and photon starvation lead to artefacts such as those shown in Figure 22 where incorrect segmentation (tissue to bone) is seen in regions of high attenuation in particular. It is possible to use a further algorithm to identify incorrectly segmented voxels, but overall uncertainty is still driven by the underlying artefacts which derives from the very basics of the measurement system itself.

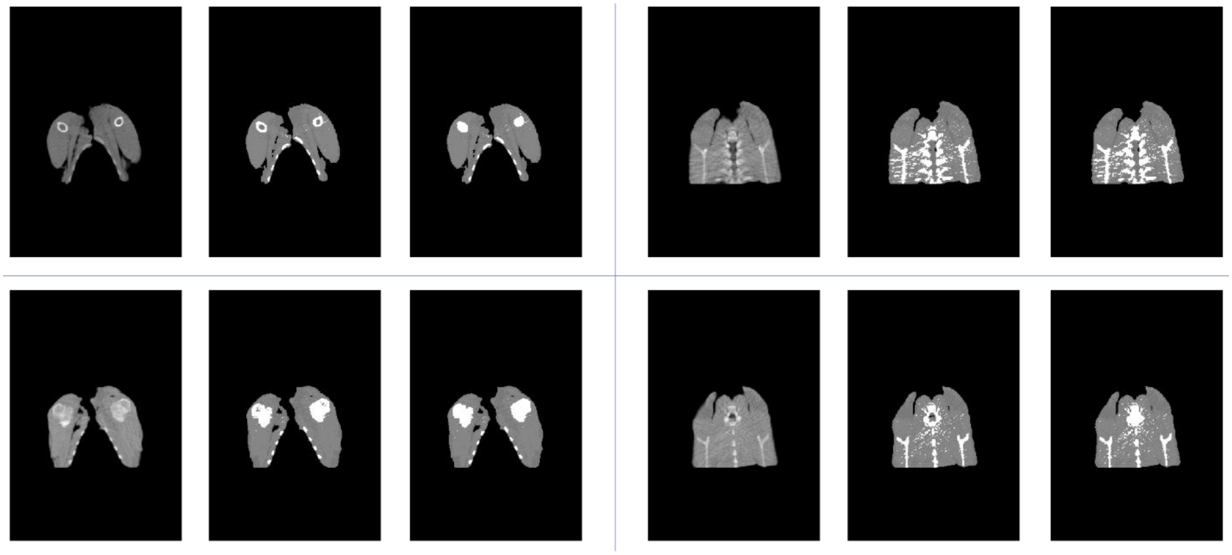


Figure 22: Example segmentation data using RTT110 scans for lamb carcasses at different positions. These show the effect of beam hardening in the thicker bone regions.

It is also recognised that for there to be a direct comparison between RTT110 and medical CT, the slice thickness should also be taken into account. In the aviation industry, high spatial resolution is maintained in all three directions (X,Y,Z) in order to maximise the chance of detecting fine wires, sheet explosives, detonators and other elements that might be found in an improvised explosive device. In contrast, the medical industry recognises that people are somewhat cylindrical in shape (from head to foot) and so a wider slice thickness is accepted in order to reduce X-ray noise (in particular the photon starvation artefact referred to above).

To demonstrate this effect, the data in Figure 23 shows a medical X-Ray CT slice from a particular lamb to the left and slices of the same lamb from the RTT110 scanner to the right. When conducting the experimental work, the Murdoch University team selected a 10mm slice thickness for the medical CT scanner. This is a standard setting for a medical CT scanner. The RTT110 always reconstructs slices with a 1mm slice thickness resulting in the scan to the top right of Figure 23. Note that the patient bed of the medical CT scanner is curved while the conveyor bed in the RTT110 system is flat. For this reason, the carcass shape appears different in the two images. When the RTT110 data is summed up over 10 slices to create the equivalent of a 10mm slice thickness, the result is the image data shown to the lower right of Figure 23. Although still not of medical CT quality, the subjective appearance of the averaged RTT110 image data is much closer to that of the medical CT scanner than the single 1mm thick slice data.

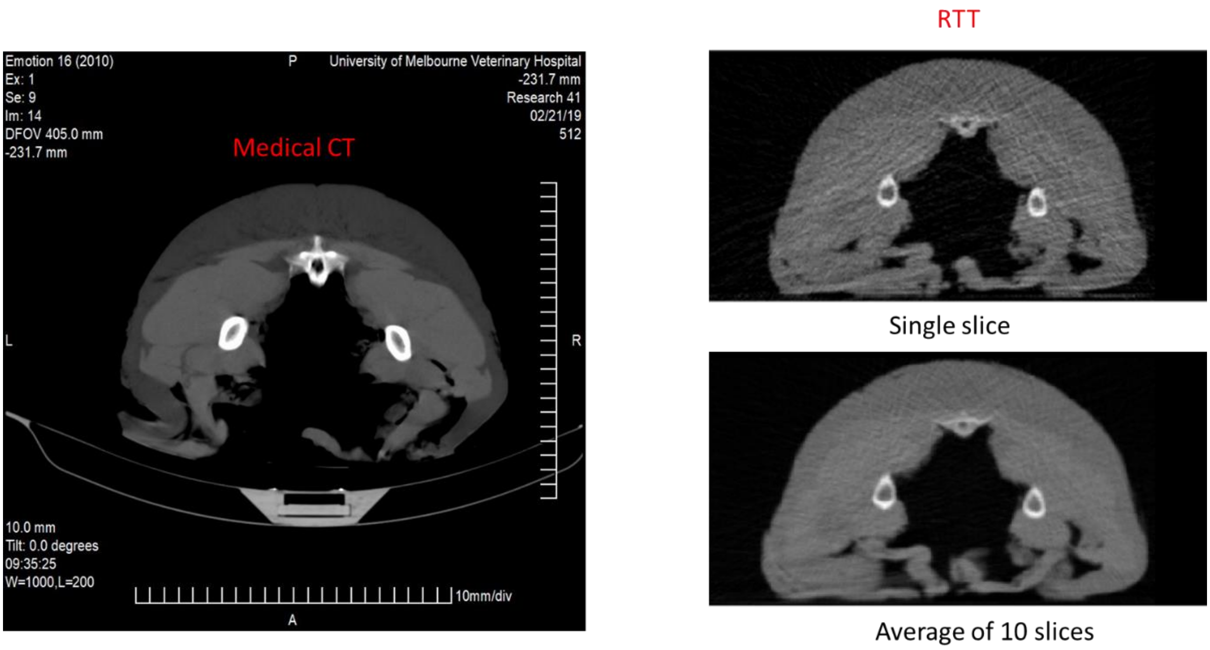


Figure 23: Comparison of a medical CT slice through a lamb carcass (left) and equivalent slices from the same carcass obtained with RTT110 for a single 1mm thick slice (upper right) and for an average of 10 slices (lower right).

This promising result shows the in-principle potential for RTT110 as a real-time on-line system for calculating Objective Measurements in the red meat industry. However, significantly more work will be required to really optimise RTT110 for application in the red meat industry.

As described in sections 4.4 and 6.2 of this Final Report, Rapiscan Systems sees the need to re-optimise the imaging chain specifically for the red-meat industry rather than the aviation industry. Further, there is a need to re-design the shape, materials used in, and build process of, the equipment to ensure food safe operation. There is also the need to develop optimised imaging algorithms for accurate Objective Measurement together with software for efficient integration with plant management and automation systems.

4.4 RTT110 Image Reconstruction Upgrade

To start the re-optimisation process of the RTT110 for the red meat industry, two technology developments were completed:

1. Re-design and subsequent upgrade to a lower noise, higher performance X-ray sensor.
2. Implementation of the image reconstruction code as described in section 3.4 of this report.

An RTT110 unit at the Rapiscan Systems factory in the UK was used for the upgrade program since it was easier for the Rapiscan Systems team to work at a factory location rather than in a field situation with the MLA RTT110 unit in Australia. The upgrade was completed in early 2020.

The new sensor design used a different X-ray detection material (slower but brighter) than the production aviation unit plus the critical analogue front end and digitiser electronics was transferred to a new technology and circuit architecture. This involved a new ASIC design for this critical component. The result was a significant (factor of thirty) improvement in signal-to-noise ratio which immediately reduces the impact of photon starvation artefact and hence improves accuracy of Objective Measurement in the red meat industry.

Figure 24 and Figure 25 show the first scans taken with the upgraded system. This data was taken for a packaged lamb shoulder purchased from a UK supermarket. The top scan in each figure is data collected using a standard aviation style RTT110 unit at the UK factory (identical to the MLA RTT110 unit) while the lower scan is from the upgraded RTT110 unit in the UK factory. In each case, the image presented is a single slice of 1mm thickness. As demonstrated in Figure 23, further contrast improvement would be achieved by going to the medical X-ray CT standard of 10mm slice thickness.

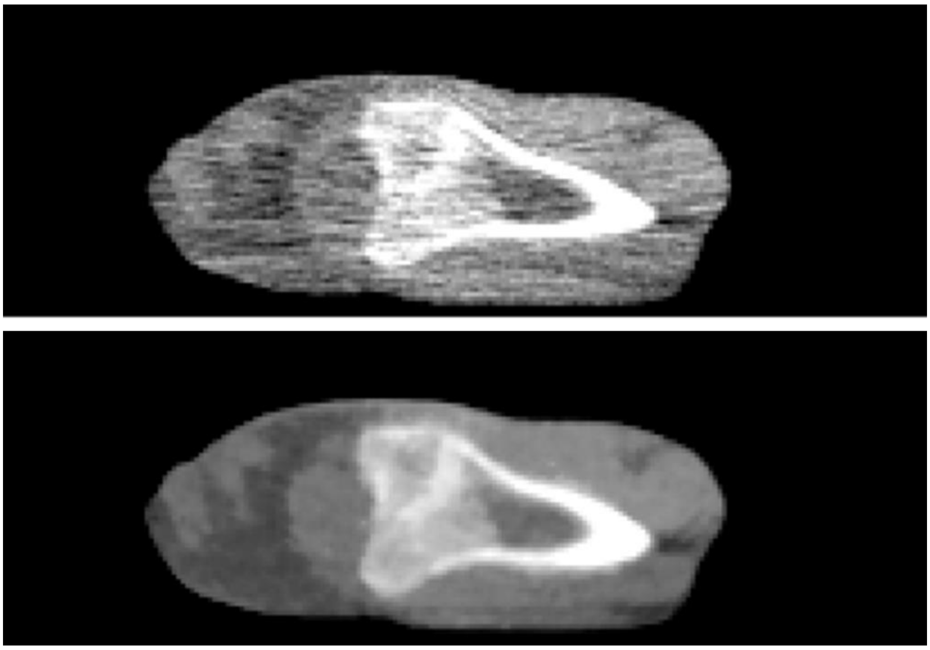


Figure 24: Lamb shoulder images on an RTT110 system before (upper) and after (lower) an imaging chain upgrade.

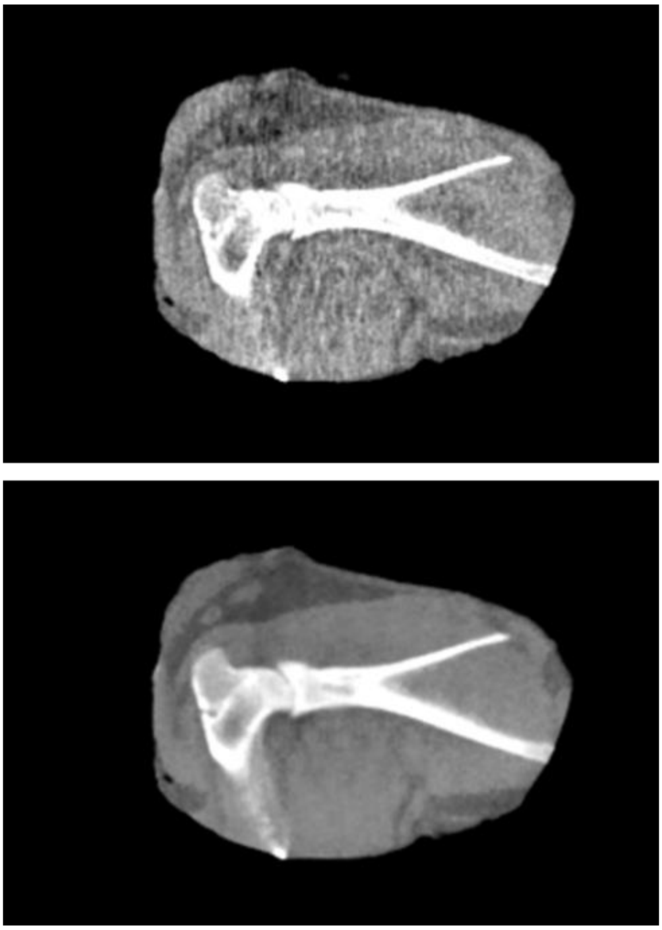


Figure 25: Lamb shoulder image on an RTT110 system before (upper) and after (lower) an imaging chain upgrade.

In each case, the image from the upgraded red meat industry RTT110 system shows a marked improvement in image quality over that produced by the standard product for the aviation market.

Given the significant improvement in image quality observed after the sensor and image reconstruction upgrades, the Rapiscan Systems team scanned a lean lamb carcass at the factory in the UK. Slices data through the back of the lamb and through the thorax of the lamb are presented in Figure 26 and Figure 27. Again, image data from an aviation standard RTT110 scanner is shown at the top and from the upgraded RTT110 scanner in the UK factory beneath.

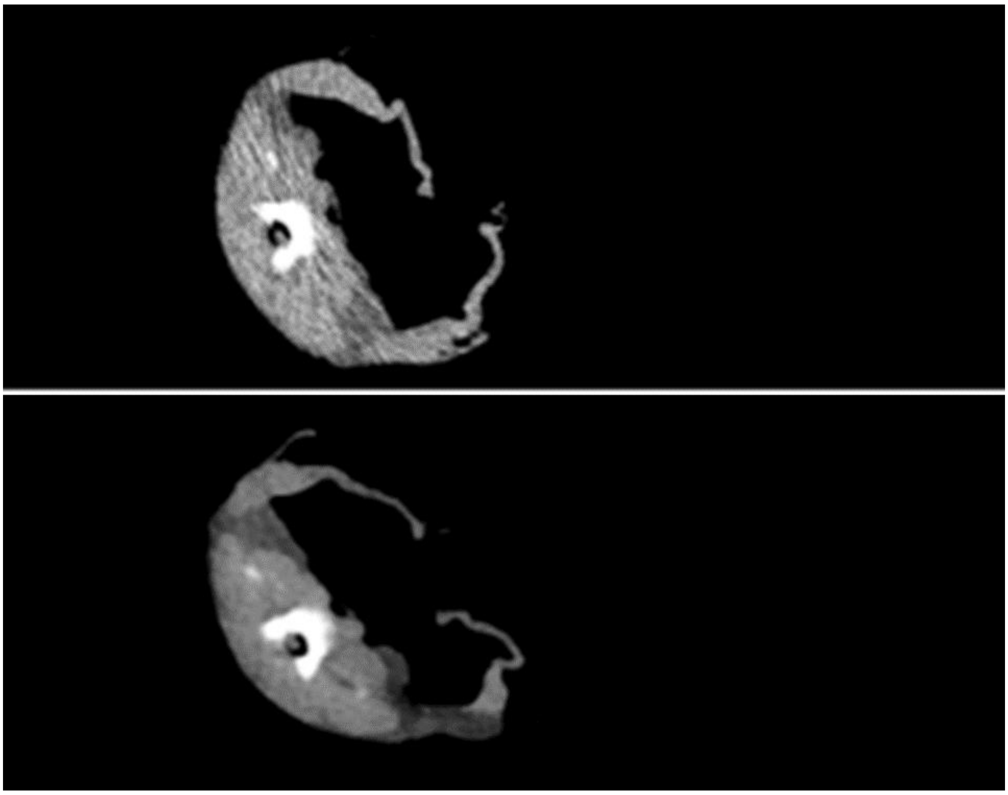


Figure 26: Images through the spine of a lamb before (upper) and after (lower) an imaging chain upgrade.

Note that the whole lamb carcass was scanned feet first in one data set and head first in the other data set hence the apparent flip in the data between the upper and lower image.

Nonetheless, there is again a significant improvement in image quality in the upgraded red meat scan data compared to the standard aviation scan data. It appears to be rather more straightforward to segment fat, lean and bone in the upgraded image data set than in the original RTT110 data set. This will lead to a significantly improved set of Objective Measurements when using the upgraded red meat RTT110 system compared to the standard aviation RTT110 scanner.

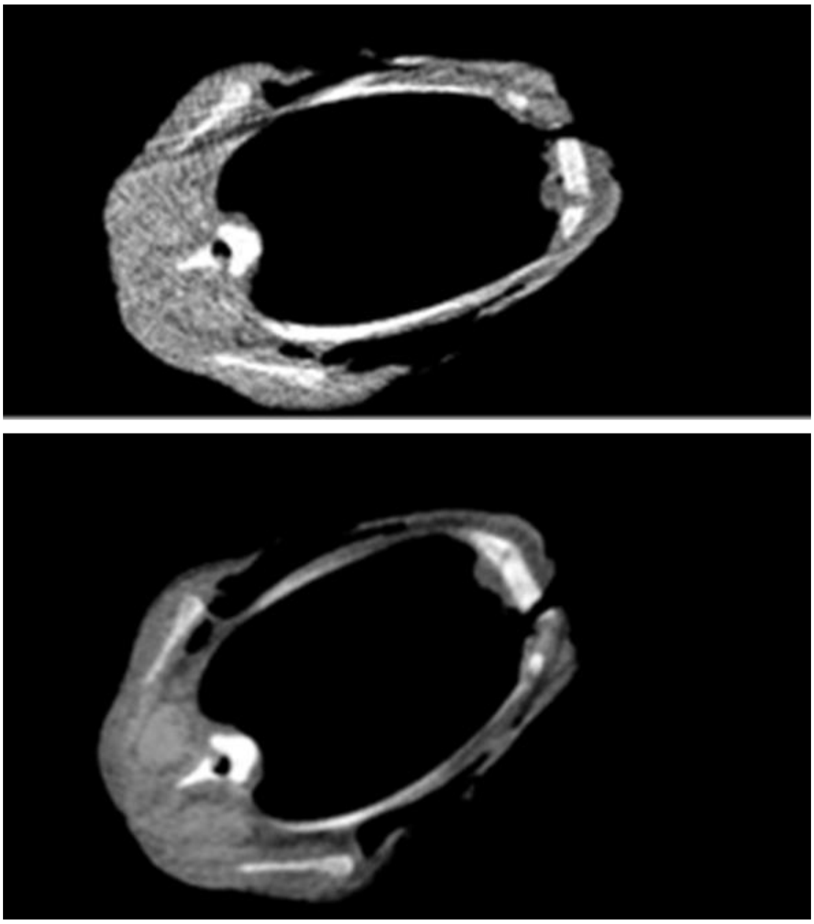


Figure 27: Images through the thorax of a lamb carcass before (upper) and after (lower) an imaging chain upgrade.

To provide a less subjective assessment of performance of the upgraded red meat industry scanner to the standard RTT110 aviation scanner, a measurement was taken for both fat and lean tissues from the lamb carcass. Here, regions of interest were defined in areas of fat and lean and statistical properties were then calculated for each region of interest as shown in Figure 28.

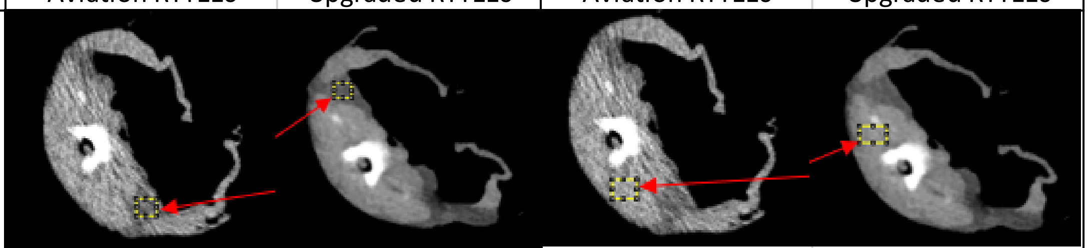
	Fat		Lean	
	Aviation RTT110	Upgraded RTT110	Aviation RTT110	Upgraded RTT110
Image				
Area	143	120	180	198
Mean	942	915	1079	1032
StdDev	49	15	43	21
Min	822	889	969	965
Max	1094	959	1173	1098

Figure 28: Raw data and sample points for the data shown in Figure 26. Note that the carcass was scanned feet first in the aviation RTT110 and head first in the upgraded RTT110 hence the difference in orientation.

To help visualise the information presented in Figure 28, the reconstructed grey levels, equivalent to 1000 x density (g/cm3), have been plotted in Figure 29. The two data points to the left represent fat and lean for the aviation standard RTT110 scanner while the two data points to the right represent the fat and lean values obtained from the upgraded red meat RTT110 unit.

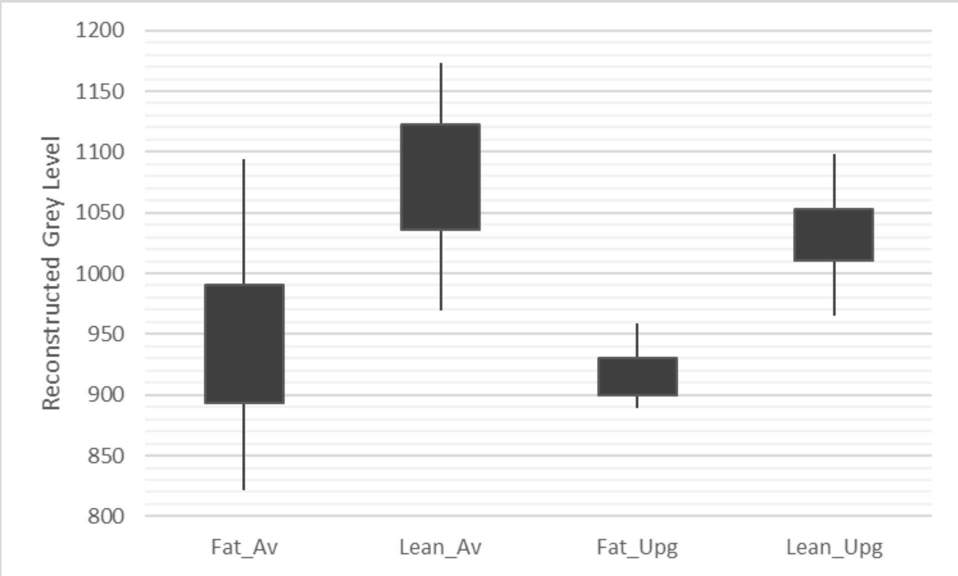


Figure 29: Comparison of Fat-Lean values from the aviation style RTT110 (Fat_Av and Lean_Av) and Fat-Lean values from the upgraded RTT110 unit (Fat_Upg and Lean_Upg) taken from the image data shown in Figure 26.

The solid bars represent the mean value plus and minus one standard deviation while the thin lines represent the minimum and maximum values recorded in the measurement.

The data clearly shows considerable overlap between fat and lean voxel values in the aviation RTT110 scan data while there is no overlap between the fat and lean voxel values in the upgraded red meat RTT110 data set. The densities for fat (0.92 g/cm3) and lean (1.03 g/cm3) compare well with literature values for these two materials when calculated using the upgraded red meat RTT110 scanner.

The upgraded RTT110 scanner therefore shows great promise for meeting the requirements of the red meat industry for real-time, process-line scanning of lamb carcasses and beef primals over extended periods at high throughput.

4.5 Project Milestone Summary and Outcomes

This was a very technical program to deliver a technological outcome – improved real-time CT scanning that can be applied to red meat industry Objective Measurement.

The key challenge of this program was to determine whether aviation standard technology can be used in the red meat industry without substantial modification. The program outcomes suggest that with an improved imaging chain (hardware, software and image reconstruction and algorithms) the aviation platform technology is indeed transferrable to the red meat industry.

5 Discussion

5.1 RTT110 Installation and Data Collection

The use of medical X-ray CT as a gold standard for determining key Objective Measurements in the red meat industry has been established in a large body of prior research and Rapiscan Systems is not qualified to contribute to this scientific or operational discussion being simply an aviation security company with a technology component that that may be suited to application in the red meat industry. This focus of this program was therefore to explore the potential for aviation screening technology in the red meat industry and not to contribute to the wider scientific case for Objective Measurement.

5.1.1 Initial Primal Scanning

The initial work done on primal screening once the RTT110 unit had been built in the Rapiscan Systems factory in the UK and subsequently installed in Tullamarine, VIC, showed that the performance of the standard aviation RTT110 system was not to the level required to deliver accurate Objective Measurement in the red meat industry.

In many ways this should not be a surprising result since aviation systems are designed to analyse a very different range of materials (explosives) than is found in the red meat industry (fat, lean and bone).

5.1.2 Murdoch University 60 lamb data set

A significant study was conducted by Murdoch University in February 2019 resulting in 60 lamb carcasses being scanned in both RTT110 and a medical X-Ray CT scanner at the University of Melbourne Veterinary School. The Rapiscan Systems team were provided access to both sets of image data in order to do a basic equivalency study between RTT110 and a medical X-ray CT scanner.

This equivalency study confirmed the result from the initial scanning work that the aviation configuration RTT110 and a medical X-ray CT scanner do not produce equivalent results. A body of work was conducted to evaluate the key differences between the two sets of image data to understand why the results were not equivalent. The top-level summary of this analysis is:

1. The signal-to-noise-ratio of the RTT110 reconstructed images is much lower than the signal-to-noise-ratio of the medical images. This makes accurate segmentation into fat-lean-bone difficult in the RTT110 images compared to medical images.
2. The total X-ray beam power produced by the RTT110 is significantly less than the typical X-ray beam power of a medical X-ray CT scanner. This much lower power operation results in the ability to work for extended periods but also drives the lower image quality for RTT110 compared to medical.
3. The X-ray beam filtration in a medical CT is much higher than in the RTT110 and this means that RTT110 systems see more beam hardening artefact than medial scanners. This beam filtration substantially reduces X-ray dose rate to the object under inspection and so in a medical CT, X-ray beam power is increased to compensate in order to maintain image

quality. This is the key reason why RTT110 can operate for extended periods in a factory setting whereas a medical CT can not.

4. The slice thickness of RTT110 is very small (~1mm) compared to the typical slice thickness of a medical CT (~10mm). This is a design decision since medical CT is looking at broadly cylindrical items (e.g. body, arms, legs) whereas the RTT110 is designed to see complex improvised explosive devices where a high spatial resolution in all three dimensions is required. In a quick test, the RTT110 slice thickness was increased to 10mm (Figure 23) and the resulting image noise was seen to reduce substantially. This result starts to show promise for RTT110 as a tool for calculating Objective Measurement results in an on-line setting

Overall, the scan data provided by Murdoch University demonstrated that the standard factory built RTT110 from the aviation industry is not equivalent to a medical X-ray CT scanner for calculating Objective Measurement data. However, some of the data showed near equivalency (e.g. Figure 20 carcass weight and carcass volume) while other data was less equivalent (e.g. Figure 21 lean meat yield).

5.1.3 Rapiscan Systems Lamb Test Data

By relaxing RTT110 slice thickness to closer to that for a medical CT scanner, RTT110 image quality gets to a closer a medical CT system image (Figure 23) but at the compromise of reduced spatial resolution. So, this is a potential solution, but it would be better to achieve high spatial resolution and good contrast resolution simultaneously.

The Rapiscan Systems team therefore invested time and resource in determining how to convert the aviation RTT110 to a red meat industry specific RTT110. The key issues to address were:

1. Improving overall system signal-to-noise ratio in order to improve contrast resolution in the reconstructed image and so improve fat-lean discrimination.
2. Maintain 1mm slice thickness with 1mm x 1mm in plane reconstructed pixels to give good localisation of bony structures regardless of their orientation.
3. Reduce beam hardening and photon starvation artefacts in the reconstructed image data.

The result was a two-part technology development program: (1) X-ray sensor re-design and (2) image reconstruction algorithm re-design. The new sensors were designed and manufactured during 2019 and a new image reconstruction algorithm was designed using an exact mathematical solution with a real-time single-GPU implementation also during 2019. The two technology programs were integrated in early 2020 in a R&D RTT110 unit located in Rapiscan Systems' factory in the UK. The first images from this upgraded system demonstrated excellent improvement in image quality (e.g. Figure 24 and Figure 25). In a more quantitative assessment of image quality improvement and analysis was done on fat-lean separation showing that the new system optimisation results in clear separation between fat-lean, sufficient for accurate Objective Measurement within individual muscle groups with voxel dimensions of 1mm x 1mm x 1mm. At this level of performance, it is possible that RTT110 could be broadly equivalent a medical X-Ray CT when looking for key Objective Measurements such as marbling given the narrow slice thickness compared to the medical CT images.

It should be recognised that this improved image quality was achieved without any change to the X-ray source or X-ray beam quality (filtration, kV or mA). Therefore, there is no reason why the newly configured red meat industry RTT110 should not be capable of 24 hour per day operation with in-line integration and real-time production of Objective Measurement at a conveyor speed up to 500mm/s. This would provide a valuable tool for the red meat industry to use in a variety of applications.

A request was made to MLA to identify qualified meat scientists with access to medical X-ray CT and a supply of primals or carcasses to visit the UK to conduct an initial Objective Measurement equivalency study of the upgraded red meat compatible RTT110 system. At the time that this P.PSH.0930 project completed, this work had still not been scheduled.

5.2 Project Objectives

Objective 1: Build a 1000mm x 650mm tunnel size RTT110 scanner with single energy detectors and scanning speed of 0.5m/s.

A standard aviation build RTT110 system was manufactured by Rapiscan Systems in late 2017 and shipped to Australia in early 2018. This system has a 1000mm x 650mm tunnel size with single energy detectors and a conveyor speed of 0.5m/s.

Objective 2: Deliver this scanner to a meat industry facility operating site of MLA's request and install it for offline use in a clean room at such facility by end June 2018.

The RTT110 unit was shipped from the UK to Australia with a packing label with address JBS Brooklyn, VIC. After arrival and while in storage at the port, it was determined by MLA and JBS that the unit would not be installed in a meat factory and it was instead routed to the Scott Automation facility in Tullamarine, VIC. It was installed in this facility in June 2018 after several months in a warehouse while Rapiscan Systems waited for installation instructions.

Objective 3: Once the scanner is installed, the image data shall be collected and used for system objectives of the Project by a team of Rapiscan's engineers to be located in Sydney.

A team of software and algorithm engineers, plus a veterinary scientist from the University of Sydney, were employed by Rapiscan Systems at its offices in Sydney. This team made considerable progress in delivering the software platform needed to deliver real-time image reconstruction, algorithms relevant to the red meat industry and efficient image visualisation. The algorithm engineers focussed on studying equivalency between RTT110 and medical CT X-ray images.

Objective 4: The data shall also be provided to MLA's collaborators on the program if agreed to under Project Variations.

No project variations have been put in place, but Murdoch University and Rapiscan Systems have collaborated and shared data on the 60-lamb data set referenced in this report. Scott Automation have also scanned various items to support their program in automation and imaging. Rapiscan Systems and Teys have also been working closely together with the result that Teys have announced Rapiscan Systems as their imaging partner for the Teys-MLA Rockhampton boning room project.

5.3 Potential for RTT110 in the Red Meat Industry

The three scanning programs referenced in this report have shown continual focus in understanding the limitations of the standard aviation industry RTT110 unit for calculating Objective Measurements relevant to the red meat industry. Alongside the scanning programs, the software, algorithm and technology development programs have delivered a new real-time imaging platform that appears to have the performance necessary to deliver significant return to the red meat industry.

Rapiscan Systems is not sufficiently expert in the red meat industry to put a valuation on the outcome of the potential programs identified above, but anecdotally in talking with processors, it seems that a scanner in each of the locations identified above would see a return on investment in typically 6-12 months.

6 Conclusions/recommendations

6.1 Impact of RTT110 on the Red Meat Industry

There are a range of possible applications for red meat industry versions of Rapiscan Systems' Real Time Tomography (RTT) technology. If products were developed and deployed across these applications, significant improvements could be made in the operational cost to deliver high quality product by the Australian red meat industry. Until the technology is proven in real abattoir applications, it is hard to speculate on the total impact on the industry, but the use of 3D X-ray scanning technology can help to deliver in the following areas:

- Reduction in staffing due to increased adoption of targeted automation systems.
- Improvement in overall yield due to accurate information on Objective Measurement within individual muscles of the carcass and potential elimination of the grading cut.
- Introduction of new meat grading schemes based on X-ray data rather than area, fat thickness and pH at localised positions on the carcass. These schemes would improve customer communication and grading accuracy.
- Improvement in operational controls, based on earlier availability of data derived from X-ray CT data (warm carcass not cold). The result is improved productivity.
- Improvement in process quality control at all stages throughout the processing of a carcass in abattoir.

Working with MLA and industry partners, Rapiscan Systems seeks to work with the red meat industry in Australia to deliver continuous improvement, including increased profitability, at all stages in the red meat supply chain.

6.2 Future R&D Proposal

To play its role as a high technology 2D and 3D sensing and real-time algorithms partner to the red meat industry within the wider program of technology driven transformation the whole sector, Rapiscan Systems is looking to develop a long term partnership with the red meat industry brokered by continuing collaboration with MLA. This collaboration should focus on two timescales: (1) short-term payback based on high performance equipment sales that deliver specific Objective Measurement outcomes and (2) Medium- to Long-term payback that results in industry transformation to a smaller workforce, technology driven business. Such transformation could equally well convert the red meat industry business model from a capital-intensive investment model to a recurring operational cost model based on per carcass outcomes.

There are many analogies here with the aviation industry in which there is a regulated requirement to conduct screening with capital intensive infrastructure. By moving to a fee per passenger basis using equipment leasing and staffing reduction driven by technological solutions, the op-ex/cap-ex balance is fundamentally shifted leading to more predictable financial outcomes.

At this time, the Commercialisation Plan that Rapiscan Systems has for this P.PSH.0930 program in the red meat industry will have minimal impact since the technology is only just starting to mature as a concept at the end of this program. The same will be true of the sister program that Rapiscan Systems is conducting with MLA, P.PSH.0886, which is developing advanced multi-energy X-ray inspection systems (both 2D and 3D) for application in both aviation and red meat industries. To generate significant impact – a goal for both MLA and Rapiscan Systems – further investment will be required to take the technology that Rapiscan Systems has and developing and apply it to three key programs:

1. Development of the Meat Science required to deliver Objective Measurement based meat grading standards, This should get to the point where, in the future, Meat Standards Australia can endorse 3D X-ray imaging as a tool to deliver fully objective, rather than the current subjective, meat grading across the red meat industry.
2. Development of the Veterinary Science required to deliver objective animal heath traits in the carcass, offal and primals. This is likely to require additional, orthogonal, sensing methods, such as the hyperspectral and MEXA imaging systems employed in the program that Rapiscan Systems is conducting with University of Sydney under the MLA sponsored V.DSP.2018 MEXA Offal Sortation project.
3. Development of food grade 3D imaging systems that should be deployed as soon as possible in industrial abattoirs to generate the data needed to support comprehensive Objective Measurement algorithm development and produce the data need to benchmark return on investment models.

6.3 Spin-Off Externality in Agriculture

As a direct consequence of the red meat industry programs that MLA had established with Rapiscan Systems, the Australia Department of Agriculture and Water Resources (DAWR) learnt about RTT110 and the R&D group that Rapiscan Systems had established in Sydney, NSW. After some discussion, also including the New Zealand Ministry for Primary Industries (MPI), DAWR and MPI established a cross-border R&D program with Rapiscan Systems to exploit the potential for RTT110 to execute automatic detection algorithms for biosecurity risk goods, including meat products that are not allowed to enter Australia due to the risk that they pose to the Australian red meat industry. As an example, when the Biosecurity meat detection algorithm went live in Australia in November 2019, within hours several raw pork meat products directly imported from China were discovered in passenger baggage. The probability of these products carrying African Swine Fever is high and their detection and confiscation provides very direct benefit to the wider Australian meat industry as a whole.

Rapiscan Systems shipped aviation standard RTT110's to both Melbourne International Airport and Auckland International Airport for use in scanning passenger bags at international arrivals for the presence of biosecurity risk goods. The RTT110 unit at Melbourne International Airport is shown at the later stage of installation in Figure 30.

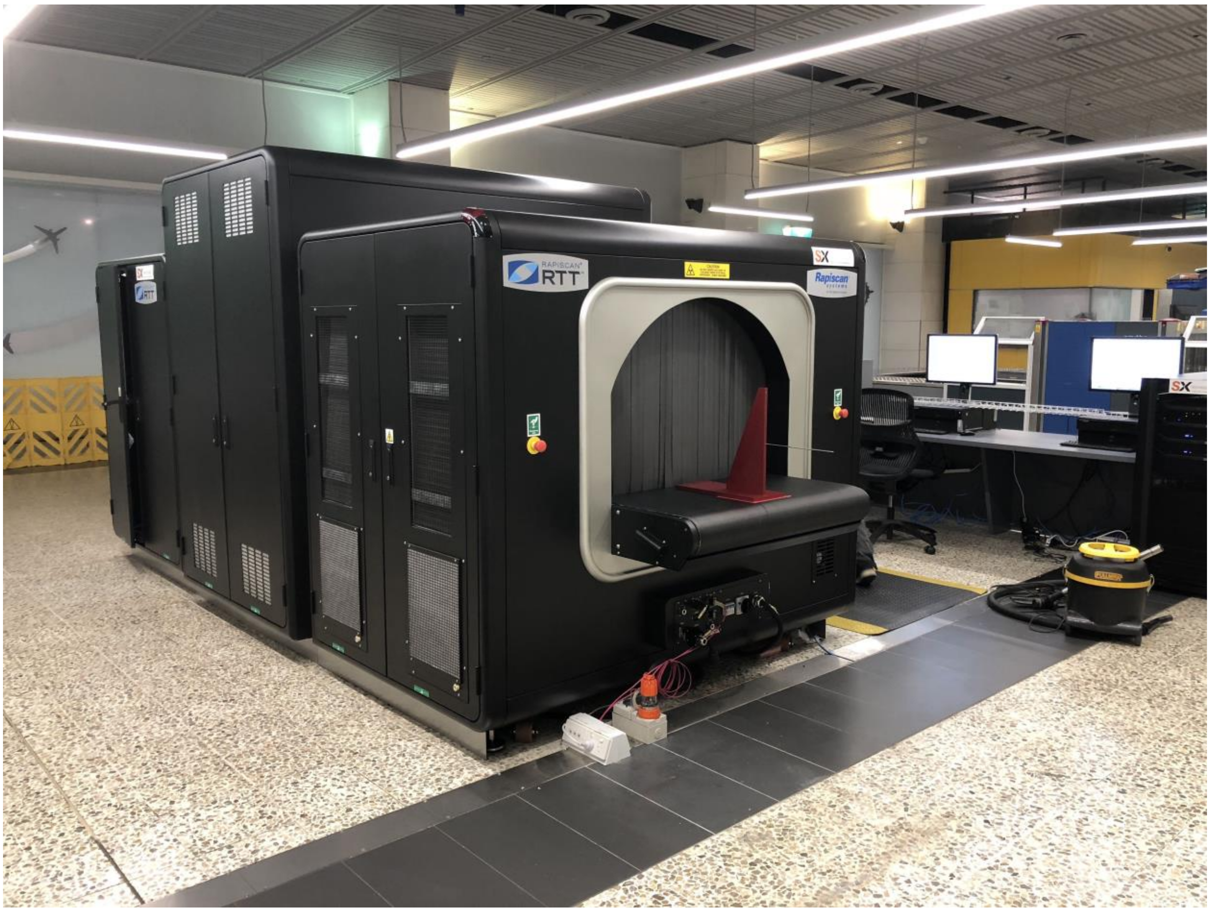


Figure 30: RTT110 in the final stage of installation at the Melbourne International Airport, International Arrivals area.

Since then, over 250,000 passenger bags have been scanned with image data for all bags stored in the cloud for Rapiscan Systems R&D staff to develop automated algorithms for detection of major biosecurity risk goods in classes of Fruit, Meat, Fish, Plants, Vegetables and Other.

The software and algorithm platform that has been developed for the Biosecurity program builds on the initial software and algorithm platform that was developed under the MLA program. The significant R&D funding that Agriculture and MPI are putting into this program now supports the wider development of Rapiscan Systems' software and algorithm platform to the direct benefit of the MLA sponsored program on Objective Measurement. The synergy between the two programs results in cost-effective R&D for all parties.

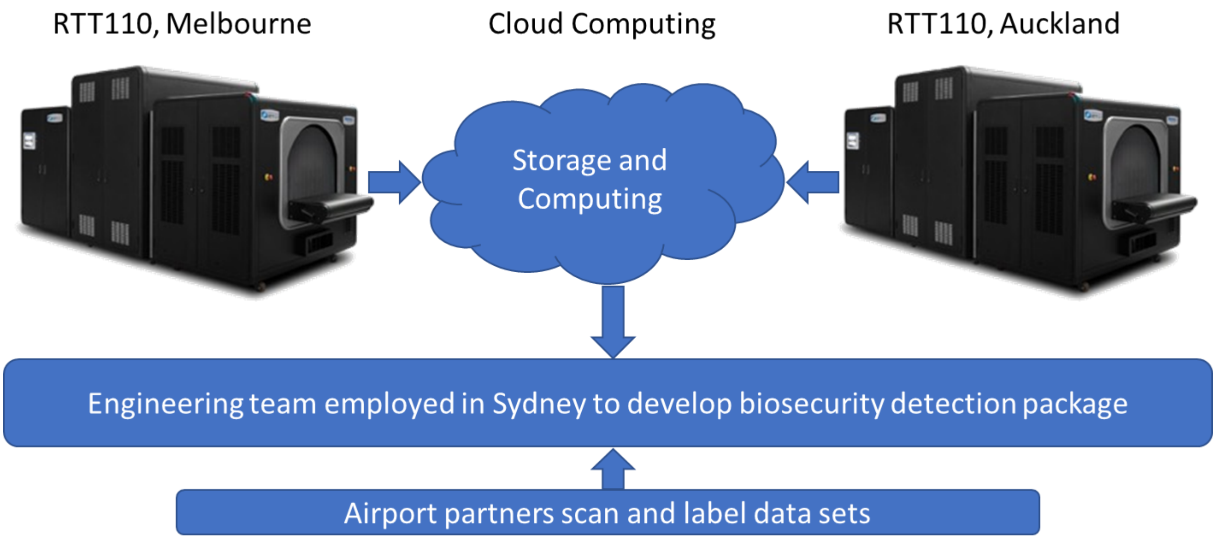


Figure 31: Overview of the Department for Agriculture, Water and the Environment program with Rapiscan Systems on automated detection of biosecurity risk goods entering Australia.

The overall scope of the biosecurity program is shown in Figure 31. The MLA program R&D team in Sydney was bolstered by the arrival of new R&D staff to work on the Biosecurity program and this increased program resourcing has supported both the further development of MLA software and algorithm programs.

The MLA RTT110 unit was taken into the Biosecurity program in mid-2019 in an effort to develop mail and parcel screening for biosecurity risk goods in addition to the baggage screening that is still in operation in the airports. The unit has generated 10,000's of images of packets, parcels and mail which the Rapiscan Systems algorithm team are now analysing. The MLA program RTT110 unit will be returned into the red meat industry program in June 2020 and . will receive an upgrade to the hardware and software configuration for red meat imaging..

6.4 Delivering Value from this Program

This was a speculative program that was designed to look at moving a technology solution from one market place (aviation) into another (red meat industry). The final results that would be achieved were unclear at the start of the program.

Through the interaction with MLA, Murdoch University and other industry partners, there is now a technology solution in play that needs to be taken to the next level of research and development by experts in the red meat industry. This is the focus of a continuing R&D program in which Rapiscan Systems remains a core technology provider with the science and industry insight being provided by partners with strong background in the field.

It is clear that with the next stage in technology, science and application development that are proposed here, the current program has the potential to deliver significant value to the red meat industry in Australia and beyond. It is recommended that MLA commission an independent cost benefit assessment on the proposed Rapiscan Systems imaging product portfolio in the red meat industry to determine likely impact on the industry as a whole.

Through the externality that Rapiscan System has actively sought to create while conducting this program, an advanced Rapiscan Systems R&D centre has been established in Sydney, now comprising 12 staff with a specialist team of two more R&D staff in Melbourne. Within the whole group there are currently 6 staff holding PhD's. This team is likely to expand further over the coming months.

This program has therefore delivered three key benefits to MLA in addition to the significant R&D outcomes of the program itself:

1. Potential to create significant bottom line impact right across the red meat industry in many different application areas, all driven by high performance imaging and Objective Measurement.
2. Establishment of a high technology Australian Centre of Excellence in X-ray and CT imaging, high performance computing, algorithms and AI.
3. Major transformative program with the Australian Department of Agriculture for automatic detection of Biosecurity risk goods. This program has the direct goal of providing significant protection to the whole of the Australian red meat industry through reduction in imported, infected, meat products from abroad and reduction of imported plant product that could destroy pastures and other natural flora and fauna.

7 Key messages

7.1 Recommended Change to Practices

At this stage, it is too early to recommend changes to practice. However, the proposed next stage in development of the program could result in two significant changes to the way that the industry works:

1. Adoption of 3D X-ray based meat grading driven by automatic Objective Measurement algorithms. This is a long-term goal but would represent a major step forward in delivering product and consistent and well-defined quality.
2. Adoption of 3D X-ray image driven automation systems across the boning room, not just for carcass separation into primals but for intricate boning work too.

7.2 Potential Economic Impact

At this stage it is also too early to predict potential economic impact from this work. However, if the R&D program stops now, there will certainly be no future economic impact.