Final Report

Smart Verification

Smart Verification Technologies for Meat Processing

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Prepared by
Stuart Smith, Graeme Baxter, Joshua Hall

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1.0 Executive Summary

The Australian red meat processing industry is Australia's largest agriculture/manufacturing sector, largest Agricultural export industry and largest regional employer. Costs associated with conducting business should be assessed and where possible reduced to ensure Australia remains competitive on a global scale. The 2020/2021 Federal Budget announcement of $328M to be spent on “Busting Congestion for Agricultural Exporters” is validation these issues should be a priority. In particular, $10.9M was allocated for building a more competitive and modern meat industry.

The adoption of ‘smart’ solutions such as AI cameras and smart glasses is one approach which can reduce compliance costs which are a significant burden on the industry. Smart technologies enable the remote or autonomous inspection of a meat processing facility and can yield significant gains in productivity, efficiency, and risk mitigation. However it is known that this goal is very complex, expensive and could take time. Bondi Labs, in collaboration with over 20 meat processors, domestic and international auditing agencies investigated how two key technological approaches could be used. This report outlines the research teams activities and outputs conducted over a period of six months (May to October) 2021.

Key highlights were:

- **Continuous Verification:** The development of an innovative AI camera prototype capable of detecting non-compliance errors on export meat cartons and an investigation into contaminants on carcasses. This project used innovations such as customised mobile camera rigs, 3D printed parts, computer vision and deep learning models. This innovative approach lead to a system which could detect meat cuts, read labels, and detect a subset of common errors. The project also utilised 3D digital twins to speed up the product development process, practice experiments without travelling to a processing site, and use synthetic data to improve experimentation on deep learning models. Smart glasses were also utilised to conduct remote onsite equipment installation and experiments, thus reducing the impact of COVID lockdowns on the project timeline.

- **Remote Auditing :** Demonstration and rollout of remote auditing technologies (Smart Glasses) to facilitate real remote audits, inspection and training for Export certification, AAO training, equipment maintenance, and animal health surveillance. The project observed over three hundred remote inspections being conducted amongst over 20 separate meat processing and audit organisations. A large portion of these led to immediate cost cuts in compliance, training and maintenance. Additionally a significant contribution to Agri-tech cyber security was also developed. A prototype solution was developed which digitally signs live streamed video data, making it immensely costly to fake or tamper with.

Continuous Verification:

The research team investigated how emerging technologies such as computer vision / deep learning techniques could be used to address known issues with quality assurance. In particular, how can camera-based sensors automatically detect and inform QA teams if a non-compliance issue is found? Two use cases were explored, Carcass contamination and Carton Label Verification.

The research team first investigated what might be possible if camera sensors were to be utilised to detect carcass contamination and provide this information to Carcass Pre-Trimmers and QA managers as a part of their Meat Hygiene Assessment role. This investigation, in collaboration with Swinburne University, discovered that there was existing research and emerging products that aimed to detect some contaminants i.e. faecal matter using different light spectrum technologies. However, there was little research that pointed to a solution in existence that aims to detect all Meat Hygiene Assessment Zero Tolerance issues such as Milk, Bile, and Faecal matter. The preliminary research work uncovered a potential avenue to solve this issue by using a combination of deep learning techniques to analyse hyperspectral images captured of the carcass. Using these two technological approaches its hypothesised that a solution could be developed to take images of a carcass from multiple angles and detect common carcass contaminants. It's at this point the project investigation paused and may come to be resumed with further investment.

The second problem case the research team focused on was an AI-based camera system called the “Box Label Verification” (BLV) system. This hardware /software system was designed to detect non-compliance issues found on carton labels for chilled products? This investigation broke down this challenge into discrete parts (detect meat cuts in a carton, detect carton labels, perform an evaluation of potential errors on a label). The research team then developed a modular system that combines these detection systems to capture and feedback to QA staff detected results.

Due to the limiting factors posed by COVID lockdowns, the research team primarily conducted experimentation in the lab and restricted the detection to a subset that is representative of the entire problem i.e. detecting six meat categories and 10 common label errors. In lab and field tests the BLV system demonstrated it can detect carton non-compliance issues with a high degree of accuracy.

Outcomes from both user and system testing found that QA staff saw the potential benefits to productivity, and quality assurance if the system were to be deployed and fully functional. Field tests conducted late into the project discovered that some minor modification will still be necessary both to the camera rig and software for the prototype to fully evaluate the system in an authentic setting. It is currently planned for future works on the BLV to improve on the issues discussed during recent field tests and then retest. Following this, the research team will propose the BLV is fabricated in food-safe materials like stainless steel and the detection system expanded to support over 20 meat-type categories and 60 label issues. This will get the BLV system to a commercially viable state that can assist QA teams onsite.

Other innovations discovered during this project were

- Improvement in AI data collection using statistical methods
- Rapid prototyping using 3D printed parts and readily available hardware parts
- Remote installation, configuration and experimentation using smart glasses
- Use of 3D digital twins to conduct general experiment planning, AI data collection, and BLV system simulation

During the research investigation, it was also found there would be other opportunities for the BLV system to be redeployed to solve other similar issues such as carton damage, bag leaks, staff training, and inner label confirmation. It could also be used in conjunction with other sensor systems e.g. RFID, weight scales to enhance the level of accuracy in detecting non-compliance issues.

Remote Auditing/Remote Inspection

The research team continued to investigate how remote inspections using emerging technologies like smart glasses see (Figure 1) could help lower the cost of compliance for the industry. This part of the project is a continuation of previous AMPC research projects which successfully demonstrated remote inspections for audits could happen if the participants, technology and network infrastructure were appropriate. This project part worked with over twenty organisations including auditors and meat processors to trial the use of a remote inspection software and hardware solution, as well as provide feedback and input into new remote inspection software features.

Figure 1: QA Inspection staff member user smart glasses

A range of new software features was developed during this time which came to be user tested with industry participants e.g. capture high-quality image data and sharing that with auditors in real-time. Paramount to the use of remote video stream and data collection tools, is the security and privacy of the data. The research team engaged with the University of Queensland's Cyber Security Research Group to understand potential future gaps and weakness in a remote auditing cloud solution. Whilst the current software solution was found to be secure, potential future weakness were found i.e. the ability to easily fake a video or image and use it maliciously against a meat processor. The research team investigated this issue and developed an innovative prototype that demonstrates how a video stream can be digitally signed and authenticated and is exceptionally expensive to fake. This prototype solution was found to not impact the performance of the video stream on higher end PC's. Future work will aim to improve the performance of this system as well as integrate it into the Bondi Labs Elixar remote inspection software.

The project also developed new remote inspection operational procedures that were refined with industry participants. The goal for this was to ensure both the meat processing QA team and auditor are thoroughly prepared to conduct an audit and understand how to handle technical issues that may occur. An analysis of common audits standards was also performed to understand how much could be assisted with remote inspection technologies. It was found that over 75% of some audits can be comprised of visual inspections which could be supported or replaced by a remote inspection. Even audits that include documentation checking could be assisted using remote inspection technologies e.g. screen share functionality and secure digital document sharing.

In summary, over 300 remote inspections were observed and analysed. Many more inspections were conducted which the research team was not privy to. Feedback from these remote audits was generally positive, with all participants seeing both the value and usefulness of conducting remote audits. The research team also observed some remaining limitations and challenges faced when performing a remote audit i.e. if the technology, WiFi, or participants are not prepared, the experience can take longer than a face to face audit or become more frustrating. Audits organisations still will opt to conduct real onsite visual inspections. However, they are open to using remote inspection technologies if an onsite visit can’t be achieved e.g. COVID lockdown or short staffed. It is planned that the research team will continue to support the meat processing industry in adopting and running remote inspections and trials themselves.

The technology solution is mature and robust enough for organisations to adopt today. The hardware cost to businesses to adopt this technology is roughly $2622 + GST per site. The potential return on investment is largely based on two factors, a) usage and b) acceptance. As an indicative ROI the travel and accommodation costs of some audits can exceed $2000 thus remote audits can start covering the initial hardware costs after only a few remote audits. When you include additional user cases such as remote training and remote maintenance the ROI increase further. The last step is for domestic and international regulators to adjust their policies in relation to food quality, safety and export requirements.

2.0 Introduction

The Australian red meat processing industry is the largest in the agriculture sector ($A28.5B in 2018-2019), is Australia's largest Agricultural export industry ($A17.2B in 2018-2019), is the largest regional employer and the largest Australian manufacturing sector. In 2018-2019 the total sale of goods and services in the red meat and livestock sector was $72.5B (Meat and Livestock Australia, 2020).

Cost of compliance to industry ($200 million+ per annum) which is reflected export product prices , creates fear of losing business to competitive countries- for example South America- as they are gaining market share due to lower product cost which includes lower investment in food safety and product quality compliance. Lagging behind competitive countries because of failure to invest in technology and connectivity- again reflective in their price to market (increasing costs).

The importance of meat export to the Australian economy was recognised in the 2020/2021 Budget announcement of $328M for **Busting Congestion for Agricultural Exporters** including $10.9M allocated for **Building a More Competitive Meat Industry.** A key component of the modernisation of meat processing will be identifying opportunities to improve regulatory activities such as developing electronic processes to replace paper-based forms, bringing in 'smart' technologies for agreed verification activities and doing away with manual processes and outdated technologies to bring in administrative efficiency

What are the challenges in food safety quality control?

Key challenges faced by all meat processors are:

- Cost of compliance and mitigation of risk factors
- Meeting multiple standards and multiple marketplace demands
- Cutting edge plant and equipment, maintaining strong quality standards and building efficiencies for the business
- Need to gain competitive edge for export
- Sustain and improve food safety quality control
- Covid normal
- Emergency Response plan- for example remote support for Ante-Mortem inspection
- Highly manual workforce with a high rate of churn leading to loss of "expertise" on production floor

The cost of regulatory compliance for Australian meat processors impacts their cost competitiveness. This is especially true when competitor countries such as the United States, Brazil and Argentina are taken into consideration. In an analysis of the key operational and regulatory costs incurred by meat processors, based on data obtained during 2015-2016, Australia's regulatory burden is estimated to be more than double that for processors in the United States and Argentina and over three times that faced by processors in Brazil (AMPC, 2019).

Like many sectors, it is not unfair to to say that the administrative and operational activities involved in food safety regulation are currently far from state-of-the-art. The recent cost recovery impact statement published by the Department of Agriculture, Water and the Environment (DAWE, 2021) identifies that *"reducing regulatory cost and administrative burden; for processors and exporters of meat and meat products"* is essential to "*creating opportunities for Australian exporters to be more competitive internationally*". The process of regulatory compliance is therefore ripe for digital disruption.

Across the world industries are being transformed through adoption of technology. Regulatory technology (RegTech), the application of information and communication technology to enhance regulatory processes addresses the challenges involved in regulatory monitoring, reporting and compliance, is ideally suited to addressing the burden of compliance faced by meat processors. According to the 2020 Productivity Commission Information paper on RegTech, “it can be used to support the improved targeting of regulation and reduce the costs of administration and compliance” (Productivity Commission, 2020).

A recent analysis by Deloitte (Deloitte, 2021) of companies providing regulatory technologies suggests that multiple of the key challenges faced by meat processors can be addressed through technology, including:

- Regulatory reporting
- Risk management
- Identity management and Control
- Compliance and
- Transaction Monitoring.

Additionally, adopting a RegTech solution to enable remote inspection, allows business to meet future needs as well such as:

- High food standards and high marketplace demands
- Global importing interest and expectations leading in a lowered error percentage acceptance
- Global pandemic and restrictions on travel and accessibility with no clear end in sight

As an activity which involves humans in the loop, the processing and supply of meat products is vulnerable to human error. Verification of food quality is also an activity that requires the perceptual, cognitive and intellectual capacities of humans and as such, is also prone to error. Fatigue, mental stress, environment and workflow constraints are all factors that are known to significantly impact the ability of humans to effectively make and act upon perceptually informed decisions. Verification tasks are also time consuming and cannot be engaged for every single product. Instead, quality assurance checks are frequently conducted by random sampling of products at variable times and locations in the food production process. As a consequence, quality assurance tools which provide the ability to augment and/or automate the verification process are highly desirable. In response to challenges identified by industry, we have explored development of RegTech tools which can both augment and automate regulatory processes for inspection and verification.

Remote Inspection

Global crisis such as COVID-19 causing travel restrictions and bans is creating significant challenges for businesses to ensure their equipment continues to operate, the food they produce is safe and staff are trained to perform their duties. Inspection's agencies such as AUS-MEAT,DAWE, and HALAL inspection agencies who have a mandate to up-hold and enforce standards in the industry are struggling under these ‘new normal’ conditions. Additionally, there is a great deal of overlap between visual inspection audits performed onsite.

There is evidence to suggest that global accreditation and conformity assessment bodies are receptive to, and accepting of, the use of technology for provision of certification, inspection, testing and related accreditation activities. In a joint survey recently published by the International Accreditation Forum, the international Laboratory Accreditation Forum and the International Organization for Standardization (IAF/ILAC/ISO, 2021) of over 4000 accreditation and inspection professionals addressing the uptake and use of remote inspection technology platforms during the Covid crisis. Close to 57% percent of respondents had participated in a remote audit and of those, 70.7% were satisfied with the experience while only 3.7% were dissatisfied. An overwhelmingly large number of respondents (73%) agreed that new technologies, like real-time camera feeds, artificial intelligence etc, should be used to ensure continuous improvement, robustness and trustworthiness of audits, Of interest, only 37% of respondents agreed that, in an ideal circumstance, a virtual audit provides as much confidence as an onsite audit. There is therefore, further work required to provide evidence to the audit community that remote tools are a viable alternative.

Autonomous Box Label Verification

The cost to detect, and then rectify food safety/quality issues in meat processing facilities is a significant burden on Australia's ability to remain competitive in global markets. Common problems such as mislabelling on meat export boxes have been known to incur extreme economic punishments such as export bans and loss of business. These often-unavoidable issues occur because of human and mechanical errors, requiring expensive, labour-intensive visual Quality Assurance (QA) monitoring. Meat Trim Box Labelling Export Box Labelling can be automated by applying Artificial Intelligence (AI) and Computer Vision (CV) techniques. These techniques can deliver smart real-time monitoring of the labelling process to assist plant operators in making the correct labelling decision and thus reduce human error.

Autonomous Carcass Verification

Beef carcass contaminations may be a direct cause of foodborne diseases, a potential cause for the drug resistance of human pathogenic agents, and consequently is high risk and zero tolerance issue for food industries. Some techniques that are currently employed, such as pre-washing and "dag" removal, require a human visual inspection, microbiological culture analysis, bioluminescent ATP-based assays, and/or antibody-based microbiological tests. However, these methods are labour-intensive, time-consuming and expensive. Although some technologies (such as X-ray imaging, and spectrometer test) showed some successes in the detection of contaminations, they couldn't practically come into the production due to significant delays in processing results and incompatibility of required hardware with slaughterhouse configurations.

Cyber Security of Remote Auditing and Autonomous Verification

Collection and storage of sensitive visual data from a meat processing plant have traditionally been kept only onsite with "air gap" security i.e., not connected to the internet. Whilst this method offers a very secure way to store sensitive material, it makes it hard for that material to be shared with trusted 3rd parties. There is a large amount of visual data that could be utilised to a) complete remote audits, b) share with customers, c) improve research e.g., training machine learning object detection models. However the sharing of this data brings added security risks e.g. what if the data is tampered with or forged and used in a malicious way against a meat processor. It is for this reason; the project has investigated innovative ways to make tampering with data very expensive and difficult to achieve.

3.0 Project Objectives

The purpose of this project was to explore a range of problem areas that could be addressed by continuous verification and remote inspection technologies. However this is an ambitious objective that contains many complex activities and research questions. An approach was therefore taken to split the project into five separate project parts. Part 1 and 2 aimed to address continuous verification challenges. Part 3, 4, and 5 aimed to address challenges with conducting remote inspections and cyber security.

3.1.1 Part 1: Box Labelling Verification (BLV)

This sub-project aimed to develop a new smart video analysis system that leverages Artificial Intelligence (AI) and Computer Vision (CV) to reduce the risks of carton label issues being missed by QA staff. The system was designed to

- Be a working prototype that could be tested and deployed to a meat processing facility
- Easily moveable around different areas of the plant
- Show detected errors immediately to QA staff located nearby
- Send data to a cloud system for remote monitoring and alert
- Detect common meat cuts and carton label errors.
- Demonstrate a working prototype of the solution

3.2.1 Part 2: Carcass Contamination Tool

This sub-project aimed to investigate how Artificial Intelligence (AI) based technology could be used to automatic detect and identify Zero Tolerance (ZT) carcass contaminants such as milk, faecal and ingesta. Other research objectives set out to identify what camera sensors should be used to capture data for such a system.

3.3.1 Part 3: Remote Evidence Capture Tools

This sub-project aimed to continue developing a remote inspection software platform (Elixar) designed to support audits in the red meat processing sector. Key objectives were:

- Develop a digital evidence capture tool that can be used whilst wearing smart glasses.
- Develop new technology to support multiple auditors in a call.
- Demonstrate working solution with project participants

3.4.1 Part 4: Remote Auditing using smart glasses (Continued Rollout & Unified Inspections)

This sub-project aims to continue to provide remote auditing hardware, software support to over 20 organisations within the red meat processing industry. Key objectives were:

- Support existing and new **meat processors** and **audit organisations** conducting remote inspections
- Develop new inspection training and operating procedures
- Help support new inspection use cases

3.5.1 Part 5: Elixar Cyber Security and Cloud-based data centre for the Red-Meat Industry

This sub-project aims to enhance the existing cybersecurity capability of the remote inspection software platform (Elixar). Key objectives were:

- Create a secure cloud storage solution for collected research data i.e. raw data collected to train AI models
- Research cyber security gaps in live streaming and data capture technologies
- Develop new approach to increase the cost of cyber security attack on audit data
- Demonstrate a working prototype of the solution

4.0 Methodology

Within each project part are four phases each lasting 1-2 months (Research, Design, Development and Testing). The following outlines the activities and deliverables of the research team for each project part / phase.

Part 1: Box Label Verification Methodology

This project part set out to explore the following research questions.

- RQ1: Can an AI based- model detect common meat cuts in a carton?
- RQ2: Can an AI based-model count the amount of meat cuts in a carton?
- RQ3: Can an AI based-model detect label non-compliance issues?
- RQ4: Does highlighting these risks to onsite inspectors improve task accuracy, efficiency?
- RQ5: Where else in the business can this solution be used?

The following table see (Table 1) outlines the research activities and deliverables that were conducted to address the research questions.

Table 1: Part 1 - Box Label Verification Activities and Deliverables

Research	
Activities	• Data collection onsite at meat processing plant (Greenhams, Moe, VIC) • Design of the data capture rig • Experimentation with camera sensors and ML algorithms
Deliverables	• User Needs Report • Box Labelling Verification Literature Review
Design	
Activities	• Data collection onsite at meat processing plant (Greenhams, Moe, VIC) • Data cleanup and annotation • AI/ML architecture prototype/design • Meat identification model design • Label detection model design • Development of the data capture rig • Development of simulation digital twin for synthetic data collection • Prototyping with camera sensors and ML algorithms
Deliverables	• Box Labelling Design Documentation • Box Labelling verification data • Box Labelling Verification Problems Matrix

Development	
Activities	☞ More Data collection of labels from project participants ☞ Development of the BLV rig ☞ Development of simulation digital twin (carton conveyer belt) ☞ Development of AI/ML architecture ☞ Development of meat type detection and tracking ☞ Development of label analysis pipeline ☞ Camera Image Sensor Testing ☞ Implementation of CV/OCR methods ☞ Implementation of natural language processing for label word identification ☞ Development of local and remote monitor website.
Deliverables	☞ Box Labelling Development update ☞ Box Label Verification Rig, Camera system ☞ Box Label Verification Software System
Testing	
Activities	☞ Box Labelling development and onsite testing ☞ Software System Iteration ☞ Box Labelling onsite data collection
Deliverables	☞ Revised Box Label Verification Rig and Camera System ☞ Revised Box Label Verification Software System ☞ BLV Web User Interface ☞ Test Report

Part 2: Carcass Contamination Methodology

This part of the project set out to explore the following research questions.

- RQ1: Can an AI based-model detect visual carcass contamination indicators such as faecal matter, bile and milk?

This research question was explored by completing both literature and qualitative investigations with project participants. The qualitative investigations consisted of remote interviews to better understand the needs of business and end users of a proposed solution. The literature reviews helped to explore the potential AI solution directions that could be taken as well as learn from prior research works. The following table (Table 2) outlines the activities and deliverables conducted during the research phases.

Table 2: Part 2 - Carcass Contamination Activities and Deliverables

Research	
Activities	• User Needs Report • Carcass Contamination Literature Review
Deliverables	• Research and investigation in hyperspectral camera systems, collaboration with Swinburne and RMIT
Design	
Activities	• Research and investigation in hyperspectral camera systems, collaboration with Swinburne and RMIT University
Deliverables	• Carcass Contamination Report
Development	
Activities	
Deliverables	
Testing	
Activities	
Deliverables	

Part 3: Audit Software Methodology

This part of the project set out to explore the following research questions.

- RQ1: What checklist audits could be supported using this tool?
- RQ2: Can checklists be combined to improve efficiency?
- RQ3: Can the user capture and share data whilst performing inspection tasks?
- RQ4: Can larger groups of people join a call and contribute to an audit?
- RQ5: What other technology could support/enhance this solution?

The following table (Table 3) outlines the activities and deliverables that contributed to answer the research questions stated above.

Table 3: Audit Software Activities and Deliverables

Research	
Activities	Design research for HD Image Evidence Capture, Trusted Video Transmission and Recording (Prototypical), Cloud Data Storage
Deliverables	Remote Evidence Capture Tools User Needs Report
Design	
Activities	Design and testing of Elixar remote inspection solution
Deliverables	Design of features to support remote inspection audits (Image Capture)
Development	
Development Activities	Development of features to support multiple auditors on a call. Iterative testing of developed features
Deliverables	Test Build of Software
Testing	
Activities	User testing of features
Deliverables	User test reports

Part 4: Remote Inspection Methodology

This part of the project set out to explore the following research questions.

- RQ1: Can I complete a full remote audit in real time within the processing plant?
- RQ2: What inspections in the business could be substituted or supported by remote inspection?
- RQ3: What changes to audit processes are required to conduct a remote inspection?
- RQ4: Where else in the business can this solution be used?

The following table (Table 4) outlines the activities and deliverables that contributed to answer the research questions stated above.

Table 4: Remote Inspection Activities and Deliverables

Research	
Activities	• Support for participants conducting remote inspections
Deliverables	• Remote Inspection User Needs Report • Remote Inspection Progress Report
Design	•
Activities	• Support for participants conducting remote inspections • Design of new inspection support processes and tools
Deliverables	• Remote Inspection Progress Report • Remote inspection support guides and videos
Development	
Activities	• Support for participants conducting remote inspections
Deliverables	• Remote Inspection Progress Report
Testing	
Activities	• Support for participants conducting remote inspections
Deliverables	• Remote Inspection Progress Report

Part 5: Cyber Security and Trusted Video Methodology

This part of the project set out to investigate the following research questions:

- RQ1: Can I securely record, transmit, store, and retrieve sensitive visual data collected from a meat processor in the cloud?

The following table (Table 5) outlines the activities and deliverables that contributed to answer the research questions stated above.

Table 5: Cyber Security and Trusted Video Methodology Activities and Deliverables

Research	
Activities	• Cloud security technology investigation • Access logging/auditing • Anomaly detection • Requirements gathering
Deliverables	• User Needs Report • Cloud Security Report
Design	
Activities	• Cloud security technology internal auditing • Trusted video prototype development • Camera Verification proof of concept development
Deliverables	• Cyber Security and Architecture Report
Development	
Activities	• Development demonstration of Cyber Security and Architecture of Software • Cloud security technology internal auditing • Trusted video prototype development • Camera Verification proof of concept development
Deliverables	• Test Build of Software
Testing	
Activities	• User and Security Testing of Software
Deliverables	• Test Report

5.0 Project Outcomes

Part 1: Box Labelling issues:

Initial needs analysis was conducted which included research interviews with participating organisations QA staff, documentation collection and literature reviews. This investigation aimed to understand the business challenges around carton labelling errors and get a better picture of the carton checking role. Challenges identified were:

Human error

- Misidentifying meat and recording wrong data
- Entering an error into the label machine
- Applying the wrong label
- Placing wrong meat into carton

Machine / Label print and placement error

- Errors caused by label printing or placing machine e.g. machine could run out or have low ink
- Print machine is damaged
- No Label placed on carton
- Label is covered by strapping
- Other sensor data failing e.g. scales

The investigation led to the following solution needs being identified:

- Need to respond to label non-compliance issues as quickly as possible to ensure the beef chain isn't interrupted.
- Non-compliance issue and need to quickly inform the line QA worker what is the problem.
- Organisations need confidence in their labelling processes. They also need to demonstrate this confidence to both DAWE and export countries like China.
- Some labels will have two stickers, others all info is on the one sticker, so a solution needs to be flexible.
- Improving label checking ergonomics and human factors with camera/monitor could make improvements on its own.
- Reducing reliance on human QA checking of labels means QA teams can focus on other critical control points.
- Historical lookback of all cartons checked could be valuable for label error disputes with customers or importing countries.
- Can be easily moved and is flexible to adjust to solve other carton related issues in the future e.g. carton quality or leakage

The proposed solution to these needs was a Computer Vision (CV) based Box Label Verification system which included the following three components:

- **Box Label Verification (BLV) Rig:** Camera rig to support the detection of meat pieces and carton labels.
- **Box Label Verification (BLV) Software System:** Non-compliance detection software leveraging computer vision and deep learning
- **Web User Interface:** Web based local and remote monitoring dashboards to show detected issues.

Box Label Verification (BLV) Prototype

BLV Rig:

A camera prototype rig solution was designed and built for the following requirements:

- Capture both label and box contents
- Boxes can't stop on conveyer belt to capture image
- Cameras should produce a clear enough image for computer vision and deep learning models to analyse and detect what is being seen.
- Rig is mobile and not fixed to any one spot.
- Rig can show what is being detected to users nearby or located remotely i.e. connected to internet.
- For the prototype nature of this project, it was found that the rig did not have to be waterproof but should be robust against light damage, movement and resistant to light water spray.

The BLV Rig development used a rapid prototyping methodology resulting in three separate rounds of iteration testing. The earliest version of the rig was designed to simply hold a video recording device above a conveyer belt see (Figure 3). Later designs aimed to integrate two adjustable arms that cameras could mount to the rig.

The entire system was made using off the shelf and 3D printed parts and costs approx. $3,500. The BLV consists of the following components:

- Camera Rig Frame
- 11-inch touch screen
- NVIDIA Jetson AGX edge device
- 2x Color Global Shutter cameras
- 3D printed camera and edge device mounts
- Waterproof enclosure for edge device and power boards.

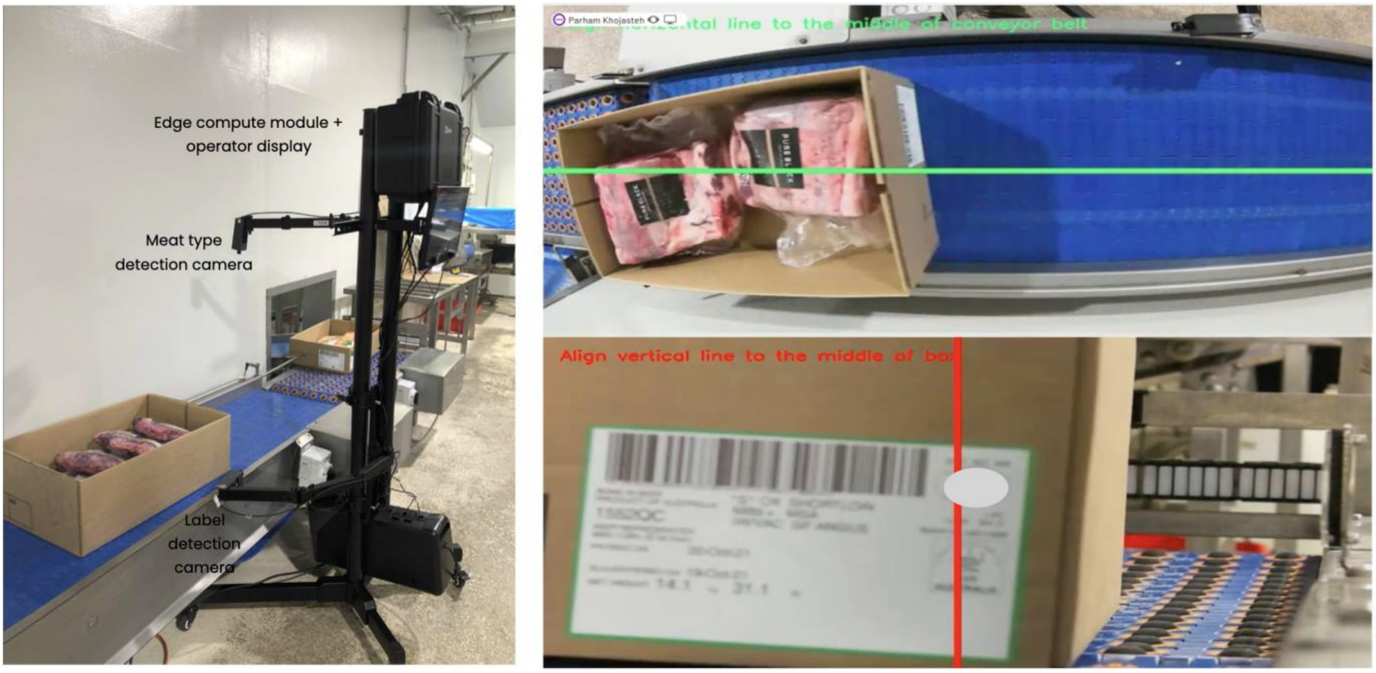

Figure 2: BLV Rig (Field Kit) Deployed to Greenhams Moe

Camera Sensors

A key part of this research was to find a camera sensor that would be suitable to capture cartons that move along a conveyer belt. Key requirements where the cameras should produce a clear enough image for both the label writing and meat in the carton to be captured as a still image and then processed using ML platform. A range of different camera sensors were assessed to see how they may perform. The following table see (Table 6) identifies the various cameras tested and a rating of their performance for Meat ID and Label detection tasks. It was found that the NileCAM25_CUXVR was most appropriate for the BLV's needs due to the testing performed. Additionally, a range of magnified lens were tested for the label detection camera. The best option being focal length of 16mm (Calculated FOV 360 x 220 mm at a distance of 1000mm). This lens gave the clearest magnified image for cartons around 600-1000mm away from the camera sensor.

Table 6: Camera Sensors

Name	Brand	Spec	Cost	Meat ID Performance	Label Detection Performance
Intel Realsense Depth Camera D455	Intel	Colour global shutter	$336 AUD (1 camera modules)	Low performance regarding the small pixel size	Low performance regarding the small pixel size
NileCAM25_CUXVR	E-con system	Colour global shutter	$700 AUD	good	good
Arducam OV9281 1MP	Arducam	Monochrome global shutter	$191.99 USD (1 camera modules)	Not applicable	Low performance for capturing a clear image of moving objects
Arducam 2MP OV2311	Arducam	Monochrome global shutter	$99.99 USD (1 camera modules)	Not applicable	Low performance for capturing a clear image of moving objects
FSM-IMX296C/TXA_Devkit-Single-V	Framos	Colour global shutter	$498.15 AUD (1 camera modules)	Hardware constraints- Cable length limitation	Hardware constraints- Cable length limitation

CV Box Label Verification (BLV) Software System

Authentic Data Collection

To develop a Machine Learning (ML)/Computer Vision (CV) system, the research team had to embark on a systematic process of collecting visual data to train/test machine learning/deep learning models on. Two sets of data were required:

- Vacuum sealed meat in cartons (Top Down)
- Export Labels placed on the outer surface of a carton

Data collection consisted of placing a camera rig at a processing facility see (Figure 3). During this time, specialised recording equipment has been provided to the meat processing QA team to continually record training data to be used in carton label verification. Over 160 hours of video footage was collected. Due to the scope of the project, the research team decided that demonstration of the system should focus on six common meat categories. Focusing on six categories resulted in over 13,000 images being manually annotated i.e. using software to draw a box around the meat, and select the correct label.

Once this annotation task was completed, the data was then automatically augmented using computer vision techniques to increase the volume of training data to over 100,000 images. Augmentation of the data included steps such as rotation, contrast, brightness etc.

Figure 3: Data Capture Rig at Greenham Moe plant

Synthetic Data (Digital Twin)

Almost the entirety of the project had to operate during Victorian COVID lockdowns in 2021. This constraint made it difficult for the research team to test the ML/CV models in the field during early stages of the project. The team did perform in-lab CV testing using printed images of meat placed on real cartons provided by the participant meat processor. However the validity of these tests was impacted by the quality of the printed images on paper. Therefor the research team decided to utilise digital twin replication of the meat processing environment and cartons. The digital twin has been developed using Unity 3D to simulate in real-time randomised cartons see (Figure 5). Raw video data is produced and passed to an edge compute device for real-time ML/CV processing.

The digital twin allowed near photo realistic representation of the convey belt, meat, and carton in a very controlled way. Using the digital twin approach also allowed the research team to pre-identify any installation or on-site usage issues before having to step foot into a plant site again. Synthetic data of both meat in cartons and randomised labels could be produced using the digital twin. This innovative approach reduced the risk of the project being significantly delayed by a pandemic lockdown.

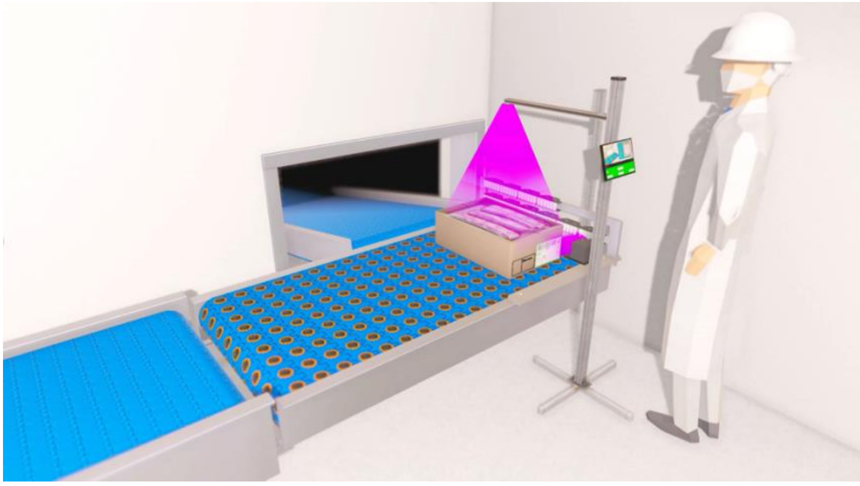

Figure 4: Visualisation of the BLV system in plant.

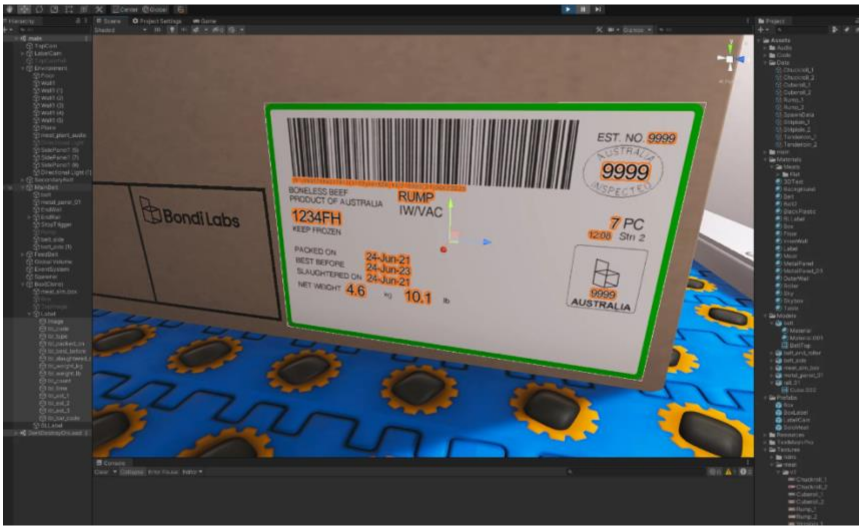

Figure 5: Synthetic data generated using simulation software (Unity 3D)

Box Label Verification Software System

Carton Label Data Collection and Non-Compliance Detection Items

The research team collected many different samples from each participating organisation. It was found that almost all meat processors develop their own format of label, and some often change that format depending on the export country and/or customer see (Figure 6). Therefore this project focused on a singular common label format provided by Greenhams. A key design requirement from this investigation was that the designed detection solution should be robust against the position of label features e.g. placement position of product name, barcode, certification stamps etc. The following table see (Table 7) outlines just some of these similarities and differences.

Figure 6: Examples of the types of different label layouts meat processors use (

Table 7: Box Labelling Verification Problems Matrix (List of AUS-MEAT, AQSIQ label requirements)

A	B	C	D	E	F	G	H
ID	Label	Problem	Example	Description	AUSM	AQSIC	HALA
1	Outer	Carton has no outer label			yes		
2	Outer	Generic Identification (Secies and Bone-in/boneless) statement is m	Boneless Beef	Bone-in or boneless sta	yes		
3	Outer	Country of Origin	PRODUCT OF AUSTRALIA	The country of origin fo	yes		
3	Outer	Country of Origin translation is incorrect or missing				yes	
4	Outer	Carcase Identification: AUS-MEAT cipher standard	*YG*	Category cipher which	yes		
5	Outer	Product Name: AUSMEAT handbook standard	SHORTLOIN MSA	Primal cut description	yes		
6	Outer	Product Name: Translation is incorrect or missing				yes	
7	Outer	Grainfed Description is missing or incorrect	GRAINFED	Identifies the product as meeting Grainfed			
8	Outer	Chiller Assessment is missing or incorrect	MB: 06 MC: 1B-3 FC:0-3	Chiller Assessment attribute statement			
9	Outer	MSA Description is missing or incorrect	GRL MSA 3 @ 5 days MSA 4 @ 14 days	Identifies the product as MSA graded with			
10	Outer	Net Weight in KG is incorrect or missing	26.2kg	The meat content of th	yes		
11	Outer	Net Weight in Pounds is incorrect or missing	57.8lb		yes		
12	Outer	Net Weight language translation is incorrect, missing or correctly applied				yes	
13	Outer	AI stamp is incorrect or missing	See AI stamp image	Australian Federal Gov	yes		
14	Outer	Refridgeration statement is incorrect or missing	KEEP REFRIGERATED	Indicates the product h	yes		
15	Outer	Refridgeration / Storage Temperature translation is incorrect or missing				yes	
16	Outer	Company processor name and address is incorrect or missing	ANY MEAT Works Co, Long Flat Road, Any	Indicates the name of t	yes		
17	Outer	Company processor name and address translation is incorrect, missing, or correctly applied				yes	
18	Outer	Piece count is incorrect or missing					
19	Outer	Packaging type incorrect or missinge.g. IG/VAC					
20	Outer	Packaging type translation is incorrect or missing				yes	
21	Outer	Slaugtered on date is incorrect or missing					
22	Outer	Packaging date is incorrect or misssing	PACKED ON 21 - SEP - 2017 14:00		yes		
23	Outer	Packing date translation is incorrect or missing				yes	
24	Outer	Best before date is incorrect or missing	BEST BEFORE 30 - NOV - 2017		yes		
25	Outer	Best before date / expiration date, storage period or self life translation is incorrect or missing				yes	
26	Outer	Carton serial/id is incorrect or missing	BATCH 448 CARTON ID: 41457354				
27	Outer	Carton serial/id /Prodcution lot number translation is incorrect or missing				yes	
28							
29	Outer	HALAL stamp is incorrect or missing or correctly applied	See HALAL stamp image	HALAL certification inspected stamp			Yes
30	Outer	HALAL stamp number is incorrect or missing					Yes
31	Outer	Establishment number is incorrect or missing	EST. NO.99999				
32	Outer	Establishment number translation is incorrect or missing				yes	
33	Outer	Customer Country Marking is incorrect or missing e.g. Origin: Austr	See Origin image		yes		
34	Outer	Label is lifted or not flat					
35	Outer	Label covered by straps					
36	Outer	Label is smudged					
37	Outer	Label is ripped / torn					
38	Outer	Label ink is to light/hard to read					
39	Outer	Forign language is incorrect/typo					
40	Outer	English language is incorrect/typo					
41	Outer	Barcode can be read and meets GS1 standards (Global trade item number, net weight, packaging date, serial number)					
42	Outer	Barcode number matches barcode scan					
43	Inner	Inner meat piece is missing Label					
44	Inner	Product Name is missing/incorrect					
45	Inner	Product name translation is incorrect or missing				yes	
46	Inner	Country of origin is missing/incorrect					
47	Inner	Country of origin translation is incorrect or missing				yes	
48	Inner	Establishment number is missing/incorrect					
49	Inner	Establishment number is incorrect, missing or correctly applied					
50	Inner	Production Lot number is missing/incorrect					
51	Inner	Production lot number translation is incorrect, missing or correctly applied				yes	
52	Inner	Label is smudged					
53	Inner	Label is ripped / torn					
54	Inner	Label ink is to light/hard to read					
55	Inner	Forign language is incorrect/typo					
56	Inner	English language is incorrect/typo					
57	Inner	Barcode can be read and meets GS1-128 standards					
58	Inner	Barcode number matches barcode scan					
59	Inner/O	Product Name matches					
60	Inner/O	Country of Origin matches					
61	Inner/O	Establishment number matches					
62	Inner/O	Production lot number matches				yes	

Object Character Recognition (OCR) and Natural Language Processing (NLP) performance.

The BLV label analysis section is composed of a combination of deep learning-based modules including Object Character Recognition (OCR), deep learning segmentation and Natural Language Processing (NLP) techniques to verify the compliance between meat type and the meat type on the label. Additional verification is performed on the text extracted from the label to ensure it meets the labelling requirements see (Figure 7).

- When testing the OCR label detections ability to extract a label and the text, it was found to have a > 90% level of accuracy.
- When testing the models performance in the BLV system i.e. detecting Meat ID and matching that to a detected label, the system also had a high level of performance > 87% accuracy.
- When testing the BLV's ability to detect if label features are or are not present, the system yields a high degree of accuracy > 90%.

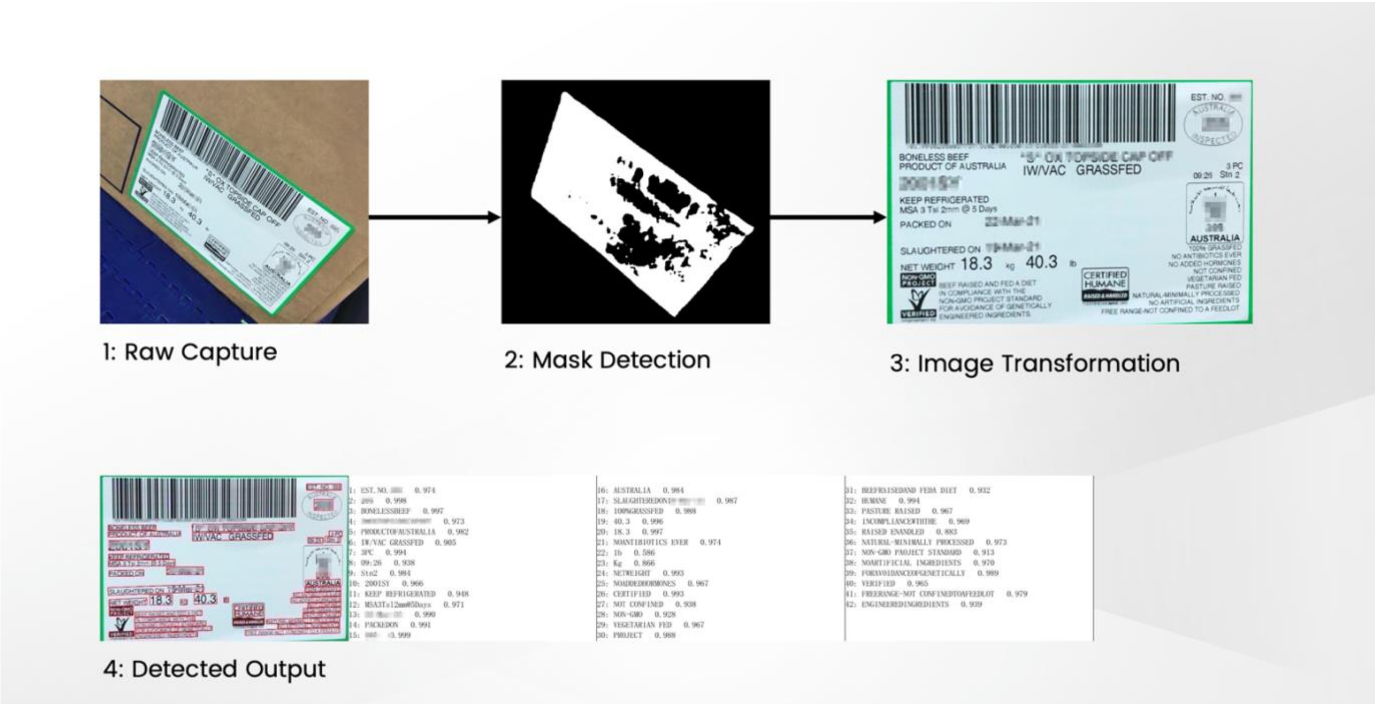

Figure 7: OCR detection process and output

Meat Detection Deep Learning Model Performance:

The BLV meat detection model was trained on over 20,000 images of meat captured from Greenhams Moe Plant. Due to the sheer number of image annotation required, it was decided to focus on training the model on six meat categories. The deep learning Meat ID model was based on mobile-ssd/yolov5 architecture followed by a object tracking model based on SORT algorithm.

The BLV system was tested within a lab environment with real data captured from previous field trips.
The models individual category performance was found to be very high for each category, and also yield a high overall performance see (Figure 8).

Final stage field testing aimed to replicate these lab results. To-date this final field testing has not been completed yet.

BLV – Sensor View Performance

Individual Piece Type Detection Accuracy

Meat Type	Accuracy (%)
Chuckroll	91
Cuberoll	99
Rump	91
Striploin	91
Tenderloin	89
Topside Cap off	90
Total Accuracy	92

Overall Meat Type Detection Accuracy

Piece Type Detection Accuracy

Meat Type	Accuracy (%)
Total Accuracy	100

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Figure 8: Model Performance of Meat Detection Deep Learning

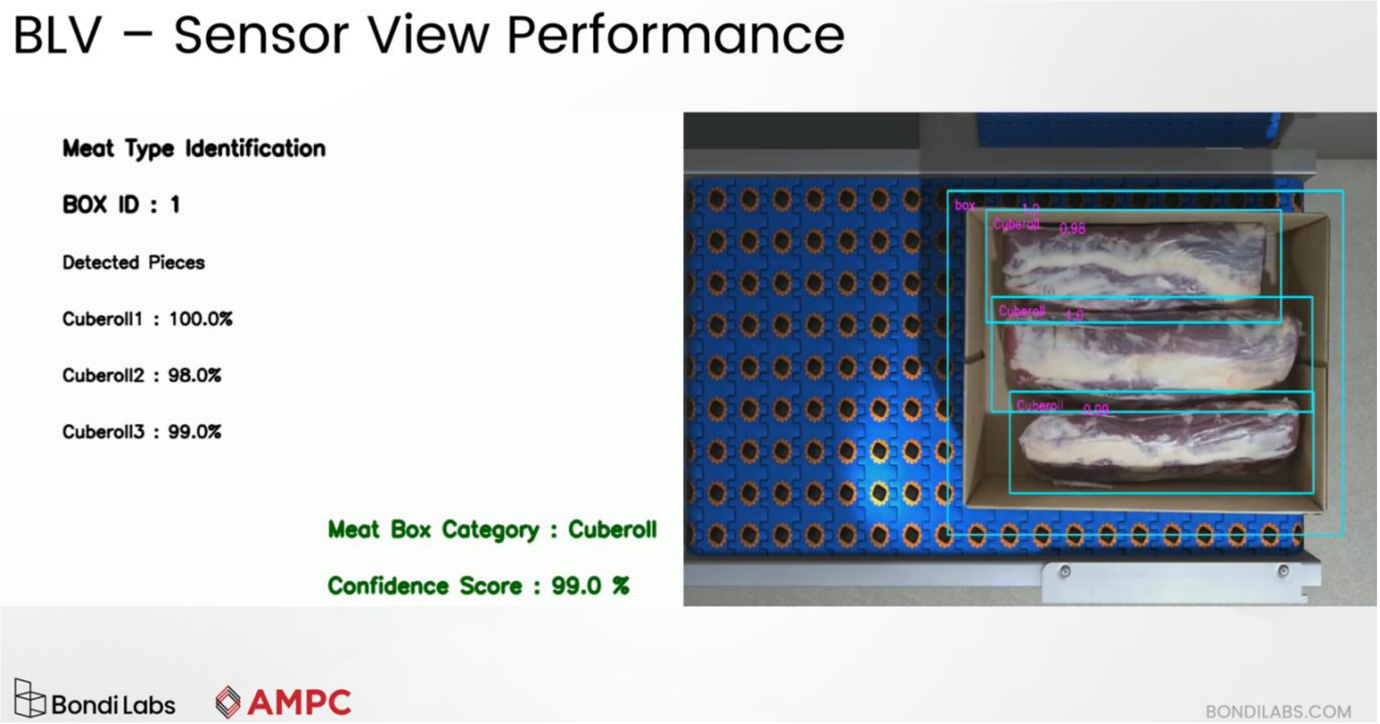


Figure 9: Detail on each piece count model accuracy performance.

Web User Interface

The output of the BLV software system is feedback to two different users:

- **Local Monitor:** Designed for Carton checker located in the plant facility. User standing Infront of BLV rig will see immediate feedback of the detection result
- **Remote Monitor:** Designed for QA manager located in office. User can review all cartons checked and investigate individually spotted issues

BLV Local Monitor

The BLV local monitor is the simplified screen presented to a carton checker worker and reflects what the camera has seen/detected in real-time. This screen is a simple website running on the edge device and takes in the camera feeds, and computed CV model output and then determines if there is an issue to report. The screen can be place anywhere close in proximity to the edge device. Output data is also sent to the Remote Monitor website for post analysis by QA managers.

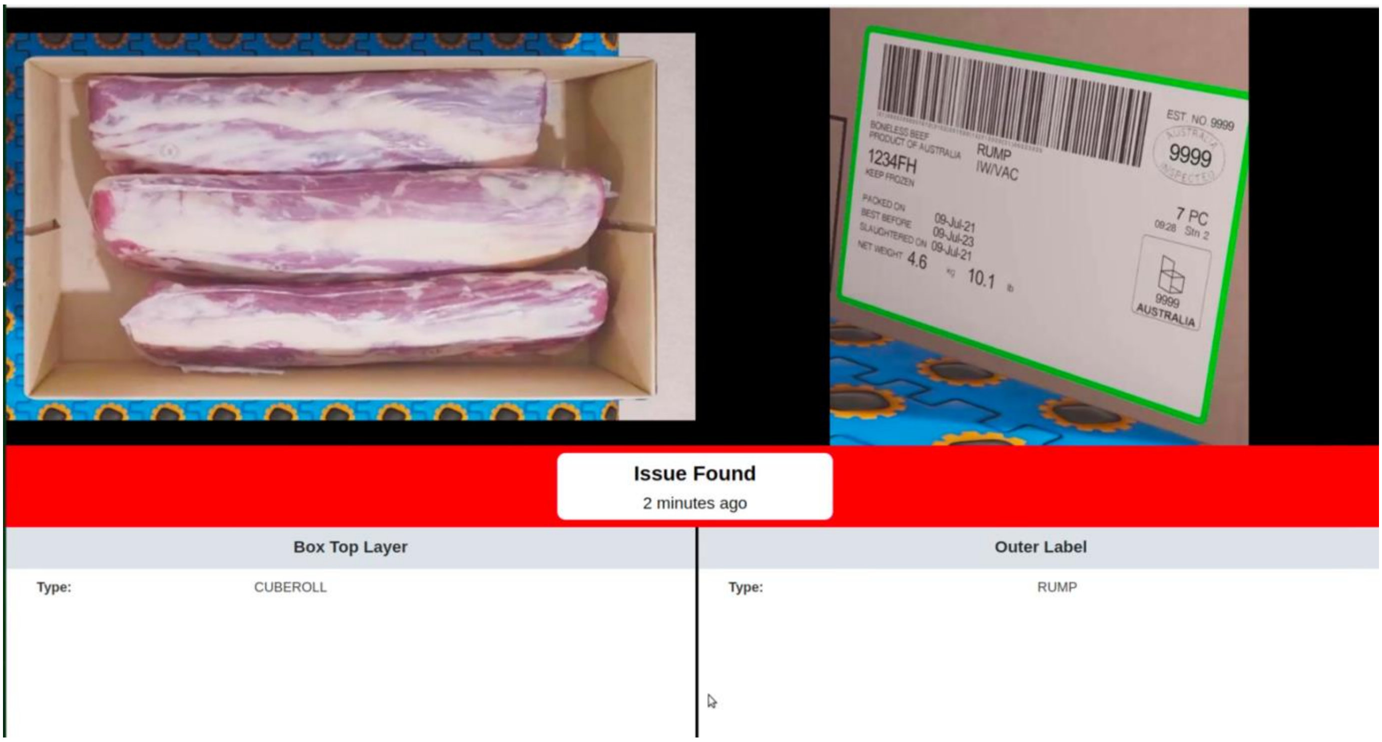


Figure 10: Local Monitor UI (Issue Found)

BLV Remote Monitor

The BLV remote monitor is a website hosted in the cloud that listens to all the BLV systems deployed. Data being pushed from each verification system is collected and can be reviewed in detail. The dashboard is designed to both record all cartons scanned and highlight cartons that have issues. Issues can be investigated further to help detect if the issue is legitimate and should be investigated see (Figure 10, Figure 11, Figure 12).

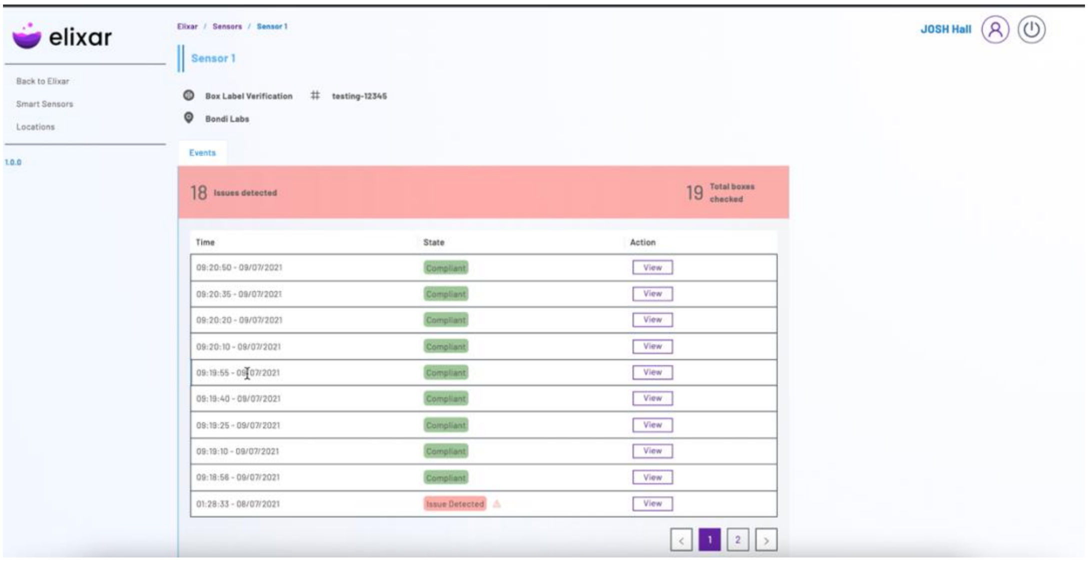


Figure 11: Remote Monitor (Cartons List)

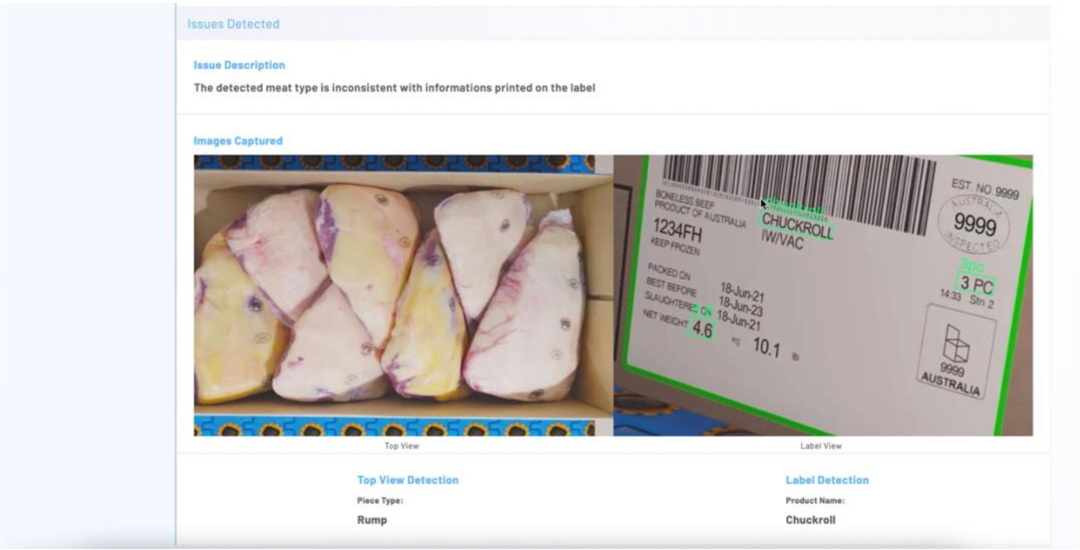


Figure 12: Remote Monitor (Carton Issues)

The software user interface was user tested with a small group of QA managers. Feedback from these sessions identified some usability issues, and other new feature ideas.

When asking the QA team their thoughts about the use of the system, responses were the following

If you could be provided information about carton inconsistencies. Would it improve accuracy and efficiency of the whole boxing process?

QA6: "My Word it would, Just thinking from a QA's perspective it would potentially eliminate all labelling verification issues. You still would have your operator checking labels, but you would have a machine checking after, eliminating all labelling issues"

What other uses could the system be used for if data is captured and made available at any time?

(QA7): "I think it will help with our training."
QA7) "Would be good to see if it could be used for detecting blown bags" "After cryovac, the seals break" "could be seen when looking into a carton"
*(QA5) "*That looks like it's coming along well.. I see this being good to verify weight ranged cuts are in the correct boxes i.e.: our lamb racks are graded by weight 5 ways, which we do with different colour inserts. This would be a good verification tool for this."

Part 2: Carcass Contamination Tool

Research interviews were conducted with individuals who had expertise or held a role in QA and microbiological QA. These interviews aimed to understand the business challenges around carcass contamination and get a better picture of the contamination pre-trim inspection role. Challenges identified

Pre-Trim Visual Inspection

- Colour, texture surface e.g. roughness and size of contaminants is hard to spot by humans
- Carcasses with high body fat are challenge due to the surface contrast
- Light is needed to view the carcass at different angles, move the carcass around.
- Ingesta is fairly common but other Zero Tolerance (ZT) issues are more infrequent thus not
- The carcass may not always be stationary.
- Shadows cast inside the carcass
- Milk is harder to identify than other ZT issues
- Neck lower to the ground is hard to check

Human Factors

- Errors more likely to occur because of attention loss (end of shift, before holiday or weekend, returning from smoko)
- Some staff have been found to be trimming just to look busy

Staffing

- Trained and qualified staff are needed to do the job. Can't be done by just anyone.

Environment

- Pre-Trim inspection performed both low down and on the elevated platform often by more than one person The carcasses may not always be there for long period, so short on time to inspect. If spending time trimming losing time inspecting.

Reporting

- Reporting is paper based.
- There is slow communication of issues

The needs of a solution therefore would consist of:

- Camera solution to support the Pre-Trim Carcass inspector, QA manager and external auditing services
- Provide Pre-Trim and QA managers ability to view and check hard to see or often missed areas
- Confirm detected contaminants
- Highlight detected contaminants
- Report ZT issues via an online portal
- Highlight contaminants that are notoriously hard to spot by humans.
- Adjust to carcass position and lighting conditions.

Pre-Trimmer Role (Meat Hygiene Assessment)

The role of a pre-trimmer is to inspect a carcass for signs of contamination. The rules which they utilise to guide this inspection falls under the Meat Hygiene Assessment (Read, 2002) standards. The process aims to inspect zones on a carcass where common defects may be found see (Table 8). Defects are classified to reflect the effect of the defect on the appearance of wholesomeness of the product into minor, major or critical categories see (Table 9). A ZT detection on carcases selected for monitoring automatically rates the lot represented by the sample as unacceptable. It also triggers immediate corrective action in the form of reprocessing of the affected lot, the rectification of the process and increased monitoring, regardless of the overall conformity index for the process see (Table 10). The task of visually inspecting is performed on adjustable elevated platforms. Inspectors use pre-defined visual scanlines to methodically scan the outer and inner surface of a carcass. Found defects are cut off the carcass, with ZT issues placed in specially marked containers and reported.

Table 8: Criteria for Defects (Read, 2002, p39)

Zone	Area Included	Common Defects
Hock	hock, shank, hook hole	hair, wool, scurf, hide, grease, rail dust, stains, toe-nails
Hindquarter Outside	tail area, back, flank	rust, grease, hair, wool, hide, bruises, scurf, faeces, pizzle butts, inoculation abscesses
Forequarter outside	plate, ribs, chuck, neck, outside brisket, fore shank	hair, wool, hide, grease, stains, nodules, bruises, grass seeds, scurf, ingesta
Forequarter inside	diaphragm, thorax, spine, neck, jugular groove, inner forearm, end of shank, brisket, pleura	hair, hide, grease, stains, clots, bruises, broken ribs, ingesta, pieces of trachea and lung
Hindquarter inside	inside round, aitch bone, pelvic canal, spine, cod fat, lumbar area, kidney, ovary, abdominal surfaces, pizzle, rectal mucosa, peritoneum	hair, wool, hide, grease, rust, faeces, hanging fragments, blood clots, remnants of organs, mature udder fragments, bruises

Table 9: Carcass Defect Categories (Read, 2002, p41)

Defect Category	Description
Minor	Affects appearance; not food safety
Major	Has potential to affect food safety, or wholesomeness
Critical	Reasonably likely to seriously affect food safety, or wholesomeness
Zero Tolerance	Contamination with faeces, ingesta, milk or urine

Table 10: Classification of Carcass Defects (Read, 2002, p42)

	Minor	Major	Critical	Zero Tolerance
Faeces, Milk, Ingesta, Urine				**Any Amount**[1]
Bruises / Blood Clots	2 - 5 cm (GD)	> 5 cm (GD)	2 or more majors	
Seed [2] (Not associated with inflammation)	5 - 10	11 - 20	> 20	
Rail Dust, Specks, Hide &Wool Dust	5 - 10 scattered specks	11 - 20 scattered specks	> 20 scattered specks	
Smears & Stains (inc bile, oil & grease)	≤1 cm diam	1 – 2 cm diam	> 2 cm diam	
Hair & Wool Strands [3]	5 – 10 strands	11 - 20 strands hair/wool	> 20 strands hair/wool	
Hair & Wool Clusters, & Hide, scurf, toenails [3]	1 cluster of hair Hide < 1 cm diam	2 - 3 clusters hair/wool Hide 1 - 5 cm diam	> 3 clusters hair/wool Hide > 5 cm diam	
Foreign Objects & Extraneous Tissue [4] includes parts of other organs & loose attached mucosa	1 incidence	2 incidence	3 incidence	
Pathology [5]			**Any incidence**	

Research Background

Prior research works have investigated existing solutions designed to detect some, but not all ZT issues. For example, a faecal detection system 'VerifEYE' was developed by eMerge Interactive and named. This system was met by mixed results and has yet to gain mainstream traction. In 2019 Barlow (Barlow, 2019) examined the effectiveness of the Veritide system in a beef processing facility. They tested the device for two different system setups:

- Veritide BluLine portable faecal scanner
- Hot Spot Camera Scanner

The Hot Spot Camera Scanner is superior to the portable BluLine scanners as it can rapidly scan whole carcases for the presence of faecal detection. Their results show the Veritide faecal detection system can detect non-visual contamination events to which an intervention can be applied thereby reducing the bacterial load entering the chiller following processing. However, the portable scanners require the user to scan the carcase in a pre-determined pattern and is typically used to focus on areas of the carcase that are most likely to be contaminated (e.g. rump). the Hot Spot Camera Scanner also requires human assistance for carcasses rotation for the full-scan purpose.

Another research project was conducted by Peter Aust & Ray Sensing for Tissue Characterisation- Contamination Detection (Aust & White, 2006). Spectrometer analysis showed that ingesta and faeces on the bovine brisket meat fluoresced (give off light radiation) at a wavelength of 630 – 700 nm when illuminated by a source of wavelength 450 – 500 nm. A spike in response at around the 700 nm wavelength region can be detected for the ingesta and faeces samples

A thermal camera was used during the MLA project Interface Detection. Images applicable to the Tissue Characterisation project were obtained at this time. Promising results came from the use of this apparatus, particularly in the detection of hair on beef carcases. Gross faecal material was readily visible however as this material cooled, thermal differentiation declined quickly.

Spectroscopic technologies appear to be very promising in the selection of materials such as chlorophyll. The effect of different surfaces such as fat and selvedge on spectrometer readings should also be looked at.

Vision sensing using CCD cameras would also be worth further investigation, particularly for material such as faecal smears, ingesta spillage and seeds in sheep, as well as defects such as bruising. The limit of this method would always be the “visibility” or contrast of any contaminants, bearing in mind that most contamination cannot be detected by the naked eye. The use of light sources from the non-visual range (wavelength <400 nm, or >700 nm) in conjunction with matching detection apparatuses may be worth pursuing.

Thermal imaging would not appear to offer a wide scope for contamination and defect detection, with the possible exception of a small number of specific items such as seeds, wool, hair, or ticks, or for “internal” contamination where the bodies physical/immuno-compromised response (e.g. abscess) may be defected.

(Park, Lawrence, Windham, & Smith, 2006) have conducted research for detecting faecal and ingesta contaminants on poultry carcasses using hyperspectral Imaging. Four dominant wavelengths (434, 517, 565, and 628 nm) were selected by principal component analysis from visible/near-infrared spectroscopy for wavelength selection of hyperspectral images. Hyperspectral image processing algorithms, specifically band ratio of dual-wavelength (565/517) images and histogram stretching, were effective in the identification of faecal and ingesta contamination of poultry carcasses. Test results indicated that the detection accuracy was 97.3% for linear and 100% for non–linear histogram stretching. This article presents the research results that hyperspectral imaging can be used effectively for detecting faeces (from the duodenum, ceca, and colon) and ingesta on poultry carcasses and demonstrates the potential application for online safety inspection of poultry.

Initial Solution Design

To capture the carcass and generate a clear enough image, computer vision techniques would need to be used. The question of “What AI approach should be used” and “How should the camera system setup to capture enough clear data to analyse” was further explored in this project.

To identify and separate the contaminants-faeces and ingesta from the carcass images, we are leveraging computer vision-based semantic segmentation. In this report, we use the instance segmentation method “Mask R-CNN” for pixel classification. Each pixel of an image is assigned a specific class that denotes the represented entity. A sample data test was used to test if MASK R-CNN would be suitable. This small scall testing was found to yield promising results as a way to detect a clear cut-out image of a carcass. A proof of concept camera system design was also explored which aimed to ensure clear images can be captured of the critical inspection points on the outer and inner surface of a carcass see (Figure 13).

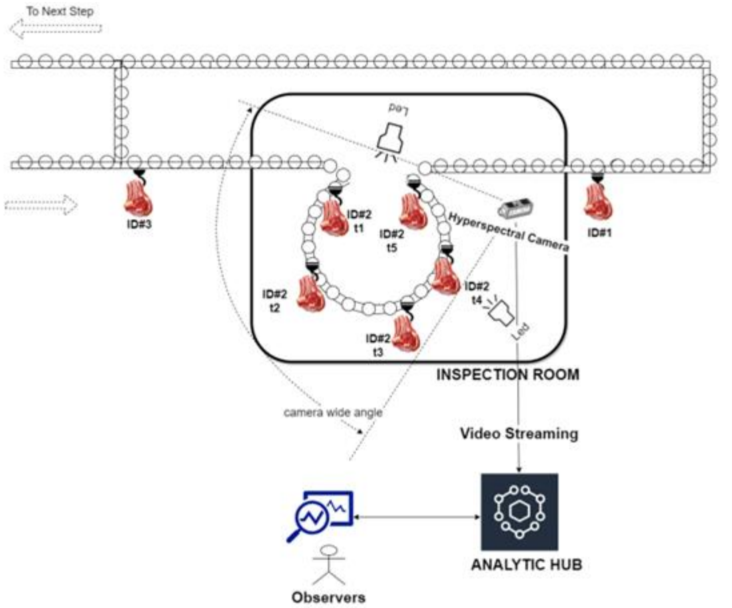


Figure 13: High-Level overview of the camera setup for automated carcass verification

Results from this investigation showed the following systems needs would need to be met:

- Hyperspectral Camera with the combination of different bandwidths. potentially, wavelengths around (700un +-100nm)
- The use of light sources from the non-visual range (wavelength <400 nm, or >700 nm) in conjunction with matching detection apparatuses may be worth pursuing. Using fluorescent lights as the source light is recommended As it emits infrared (> 700 nm) radiation which could lead to sharpen and maximize the contrast between ingesta and faeces around 700 nm wavelength
- Mask RCNN would be a suitable AI candidate to use for visually detecting contaminants.
- Quality and authentic training data would need to be collected onsite with real carcasses.
- Real samples of contaminants on a carcass would be required to train any detection models.

It was at this point, the project went on pause due to a number of reasons including project scope, COVID lockdowns, access to hyperspectral equipment and budget constraints.

Part 3: Remote Evidence Capture Tools

Initial needs analysis was conducted which included research interviews with participating organisations QA staff, documentation collection and literature reviews. This investigation emphasised the use of existing smart glasses remote inspection software called Elixar (Bondi-Labs, 2021) . This software is a custom built inspection solution designed to support audits and inspections within the food processing industry. The method of enquiry focused on understanding the business challenges around Quality Assurance (QA) inspections. Challenges identified were:

- Smart Glasses can produce Low visual quality e.g. 320x240 when live streaming in poor WiFi
- Difficult to communicate if audio quality is poor or environment is too noisy
- Can't autofocus to adjust focus and contrast
- Difficult to share an image from onsite audit to auditor during a call
- Current remote auditing solution only supported five users in a call
- Text based documents very hard to read as a remote auditor when using Smart Glasses as the capture device.

The proposed solution to these needs was to make improvements to the existing Elixar software, consisting of:

- **Understanding Audit Checklists:** Analysis of three common audit checklists from different agencies (Domestic, Export, and HALAL Accreditation)
- **Improvements to Elixar software**:
    - The auditor needs to see the high quality image captured in almost real-time e.g. within 5-10 seconds of capture to believe freshness and authenticity of the image.
    - Meat processor needs to trust that their data is secure and they have control.
    - The auditor needs to zoom in on detail.
    - Meat processor needs control over the data captured and to review after a session.
    - Communication needs to be improved if audio is poor or environment is too noisy.
- **Assistive Technologies**: What complementary technologies may be useful to assist in audits and inspections e.g. thermal cameras.

Understanding Audit Checklists:

An analysis of existing audit checklists was conducted to further investigate what audit checklists can be supported by remote inspections and could these be combined to improve efficiency. Checklist samples were collected from three separate auditing agencies:

- Local retail customer audits (AUS-MEAT)
- Export country requirements (DAWE Meat Export)
- HALAL export countries (AHDAA).

A sample copy of their common audit checklists was extracted and analysed to determine which parts could be completed remotely using visual inspection technologies like smart glasses.
It was found. Audit checklists are comprised of:

- Document Verification
- Visual environment, equipment or product checks
- Staff behavioural observations

The audit checklists were filtered using these characteristics to clearly identify the checklist items that are best conducted by visual inspection i.e. could be performed remotely see (Figure 14). The remaining elements can be audited remotely also, but via document sharing technologies like screenshare or digitally shared documents. During the project, remote auditing tools such as the Elixar Pre-Flight Check was developed to prepare organisations to adopt remote auditing technologies. The checklist is designed to clearly identify and review where in the facility they can stream a clear image, and where there is need for improvement i.e. add additional WiFi Access points, improve bandwidth limits to the facility or within the facility network. During pilot trials with over 20 separate organisations, it was found that this tool (if used) would quickly identify IT problems and provide a clear pathway to resolution.

Requirement 2 \\ M02 - HACCP — elixar

Record Required	How	Relevant areas of auditor assessment:	When seeking your goal...	Schedules
Audit Activity		a Who is the establishment HACCP co-ordinator, what is their training and experience in HACCP	**Video Quality made it:**	EC(MMP)O Schedule 2, 2.1
		b Has there been any review of the HACCP plan since the last EMSAP audit? Show me records of the last annual HACCP review	Easy to achieve ☐ Could achieve ☐	AS 4696 – 3.11(g)(ii); EC(MMP)O – Schedule 2, 12.1 & 12.2
		c What are the current CCPs for this establishment, show me the Hazard Audit Table for each CCP. Are the CCPs clearly identified on the flow charts	Struggled to achieve ☐	AS 4696 – 3.11(a), (b) and (c)
		d For each CCP review at least 5 randomly selected monitoring records	**Audio Quality made it:**	AS 4696 – 3.11(h)
		e Select one of the flow charts to verify during establishment audit observations	Easy to achieve ☐ Could achieve ☐	AS 4696 – 3.11(a)
	Camera	f **Observe the monitoring of each of the CCP CLs during establishment audit observations (note slaughterfloor Product MHA monitoring may be combined with GHP checklist activity)**	Struggled to achieve ☐	AS 4696 – 3.11(e)
		g "Discuss with operatives performing monitoring what are the critical limits, and what action is taken when the limit is breached"	Signal Drop Out ☐	AS 4696 – 3.11(f)
		h Sight records of CL failures since last EMSAP audit, was the affected lot identified and controlled, did the corrective actions follow the procedures described in the HACCP plan		AS 4696 – 3.11(f) and (h)
		i Has a HAACP review been undertaken when required (Beef STEC confirmed positive, smallstock ZT 1000 unit monitoring breach MN15/05)		AS 4696 – 3.11(g)(ii)
		j Examine daily record review evidence for minimum 5 production days since last EMSAP audit		AS 4696 – 3.11(h); EC(MMP)O – Schedule 2, 7.1
		k Examine other random records of verification activities listed in the hazard audit table for the CCPs		AS 4696 – 3.11(h); EC(MMP)O – Schedule 2, 7.1

Figure 14: Remote Audit checklist (DAWE EMSAP) identifying which items are visual inspection

This project part also aimed to identify if there was any overlap or room for efficiency in combining remote audits between related auditing agencies. This idea was discussed with all three participating auditing agencies and it was agreed that it could work but would have to be demonstrated in trials first. As a first step in this trial, the research team combined all three audit checklists into a universal audit checklist compromised of over 469 checklist items. When filtering to just those that require visual inspection, the auditing checklist is reduced to 190 items. When investigating the breakdown of inspection tasks by location, it's clear that apart from documentation checks, the Slaughter room is where most visual inspection takes place see (Figure 15). It could then be assumed that most of the inspection time is taking place in this large area, which contains many critical control points.

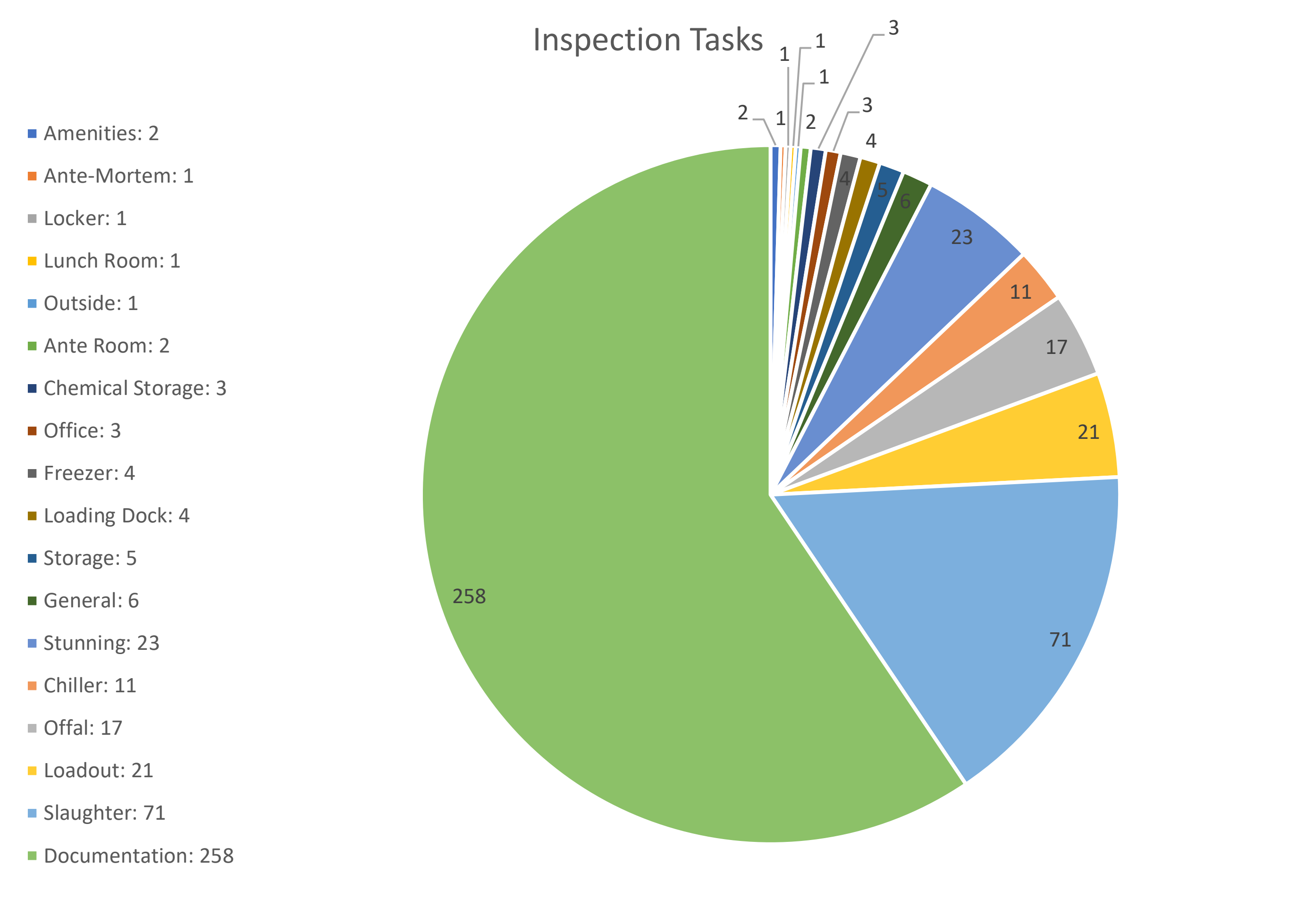


Figure 15: Breakdown of inspection tasks for a combine AUS-MEAT, DAWE EMSAP, HALAL audit

Between the three auditing organisations, the split between documentation checking and visual observations e.g. in person or using smart glasses is the following see (Figure 16).

- DAWE EMSAP Audit: 201 document, and 48 visual checks.
- AUS-MEAT: 44 document and 106 visual checks
- HALAL: 13 document, 57 visual checks

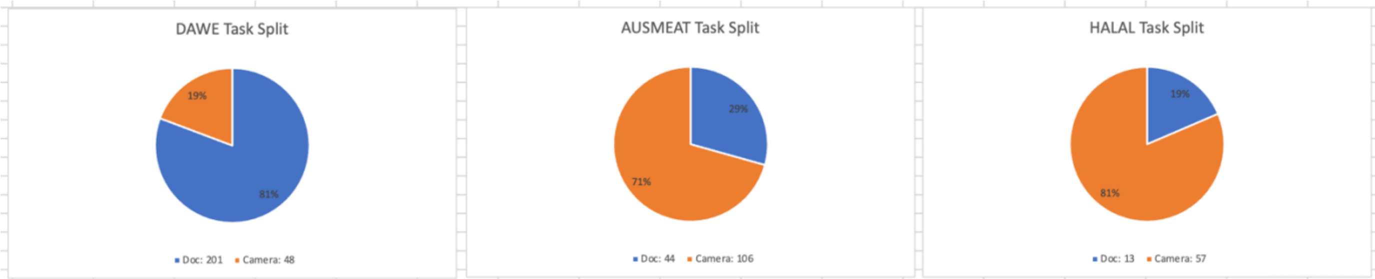


Figure 16: Inspection split between documentation and visual checks

Improvements to Elixar Software

Data Capture

User analysis outlined there was a need to produce higher quality images if the smart glasses footage was too low. The research team conducted a number of small field experiments with streaming a range of inspection items. It was found that streaming general surroundings and location at even low bandwidth conditions would still result in effective remote inspection for behavioural observations and general cleanliness checks. However under low bandwidth conditions, inspection tasks requiring high detail e.g. reading a label, sticker, document or detecting moisture on pipes required high fidelity images see (Figure 17). Therefore the team designed and built a real-time image capture and sharing system into the existing auditing software.

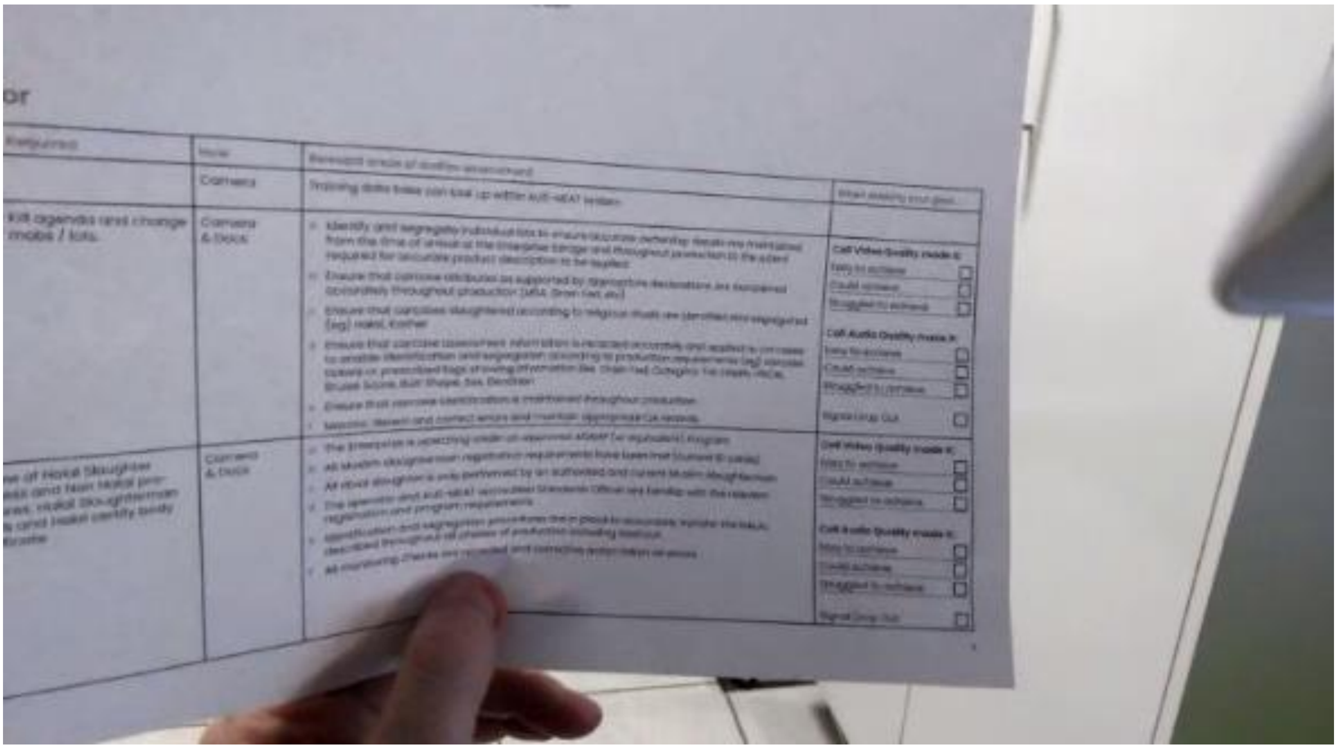


Figure 17: Low-Quality live stream vision for text based documents

User testing of this new feature with a number of participant organisations found that the data capture was able to fulfil the inspection gap found and the real-time nature of the photo capture and upload system meant that the data could be trusted as authentic and fresh. Additionally, zoom functionality was also added to increase the focus point of any images captured and shared see (Figure 18).

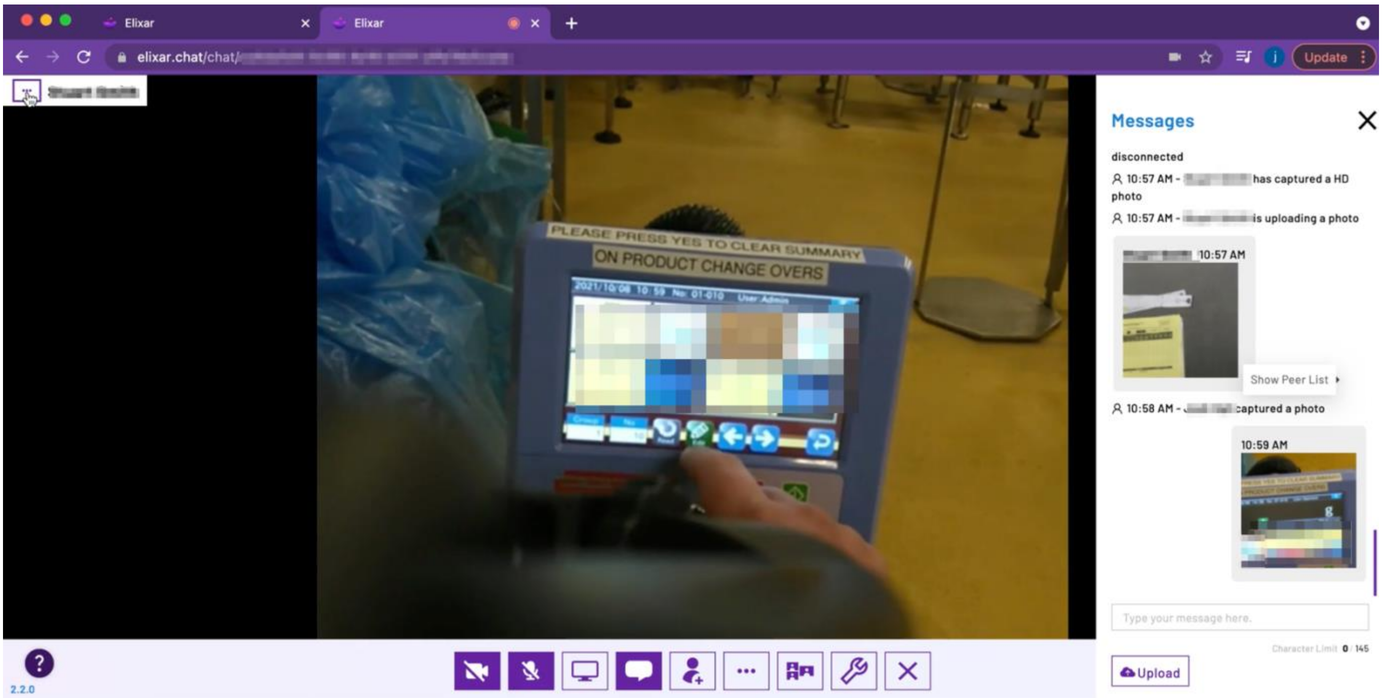


Figure 18: Elixar remote inspection solution, Image captured and shared to remote users.

Group Audits

As an example of how real group audits with multiple audit agencies involved, a real Gulf States Certification audit was conducted at the Wagstaff, Cranborne facility. This inspection connected remotely located auditors in Saudi Arabia, and Pakistan to QA staff in Cranborne, VIC. In total there were over 12 people actively involved in the audit. The remote inspection session did run smoothly leading to that facility successfully meeting the certification requirements. One auditor remarked *“see close up detail of operations that would normally be difficult or dangerous to properly inspect. For example, in the case of animal dispatch, we can use the “zoom level” feature of Elixar to get a close up view of the neck cut site to make sure that the cut has been done appropriately and to standard.”*

Impression from the QA team was *“Overall the auditors were very happy with the clarity of the video image and the sound quality. They were also happy that they could pick up on any issues of non-conformance in real time rather than rely on a previously recorded video that would be sent to them. This gave them confidence that there was integrity in the process, there was nothing that we could hide or doctor.”*

The research team also looked at methods to increase the number of participants that can join a call contribute to an audit. One approach was experimented with to use a media server solution to allow the Elixar software to support almost unlimited number of users on a call. The original web video streaming technology chosen for the first projects yield the best quality results for small numbers of users i.e. peer-peer connection see (Figure 19). Other incremental improvement were also made e.g. allowing better file management for images captured during a session. The group call version of Elixar sessions is currently in an Alpha mode for early user testing with participants.

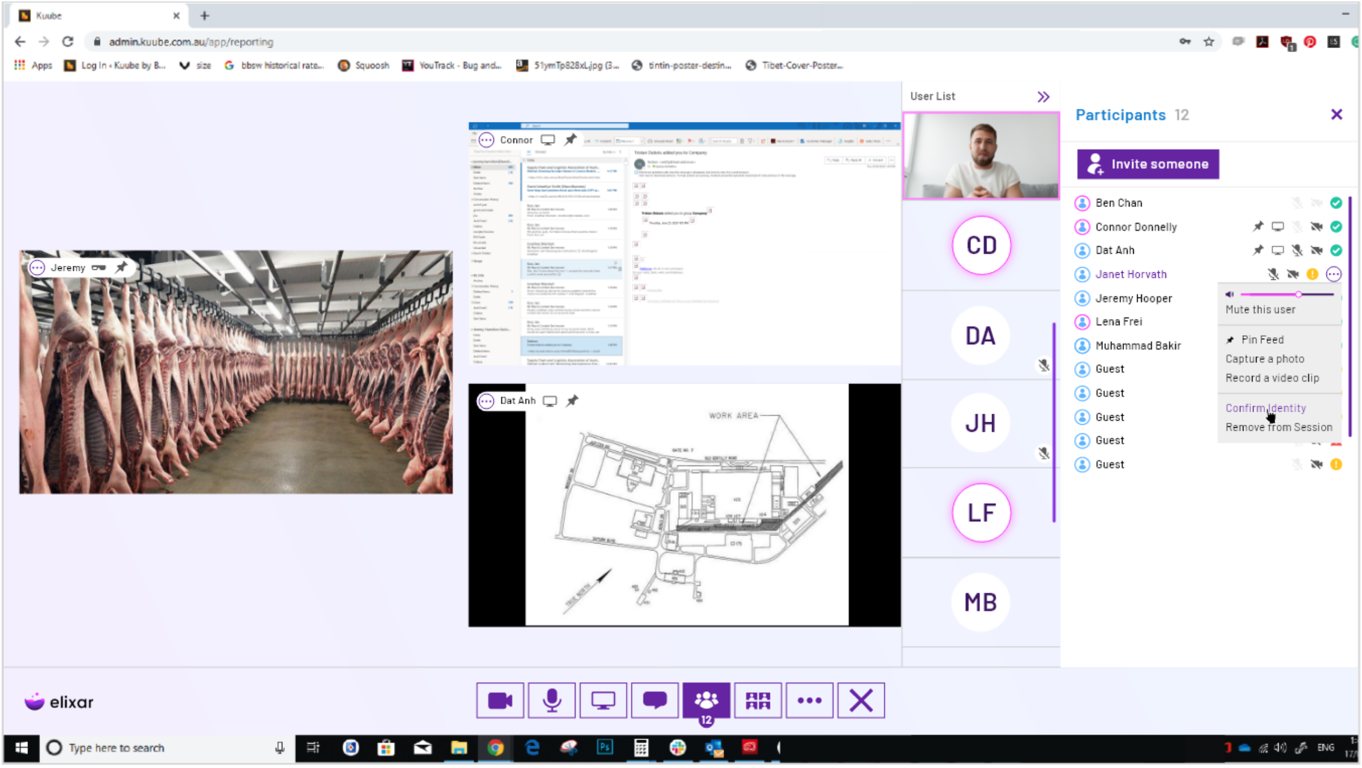


Figure 19: Updated Elixar Interface Supporting Multiple Auditors, and Trusted Video Feed Integration

Assistive Technologies to Inspection

The research team also investigated what other technology could support/enhance remote inspections. Two technologies investigated was a mobile phone and a thermal imaging camera attachment. Field tests of using these two technologies with participant organisations revealed the following:

Mobile phone as a companion tool:

Assistance	Note
Remote session information (QR or link)	Great as backup if loosing connection
Phone based photo capture	Great to take photos of things up close or at hard to reach angles with SG device
Phone hotspot internet	Good backup internet solution, but does not work inside a facility.
Backup communication method	Good if things go wrong with internet connection and quick contact with Auditor is required.
Mobile computing device for notes or access other systems	Good to quickly check other auditing systems or check email.
Uses a tool almost all users will have on them or access to.	It forces the user to use their hands to take a photo which may be unsafe or not practical if they are using hands for other inspection tasks.

Thermal camera imaging (FLIR Camera):

Assistance	Note
Quick scan of chiller or area for heat increase	Facility can heat up if there is an air leak or wall facing sun. Good to be able to visually detect where temperature risks may be in the facility see (Figure 20).
Correlate to other temperature sensors in facility	Sometimes temp sensors are placed in poor areas in a facility e.g. up high. Good tool to check difference between ambient and product temp see.
Animal Health Check	Great for quick surveillance of animals. Could be integrated into an automated system see.
Correlate with temperature probes used during inspection	The FLIR temperature readings had a tolerance of around 1 degree. This could be useful, but current temp probs need to be certified and calibrated regularly. Unlikely camera based system could compete with accepted and certified thermal instruments.

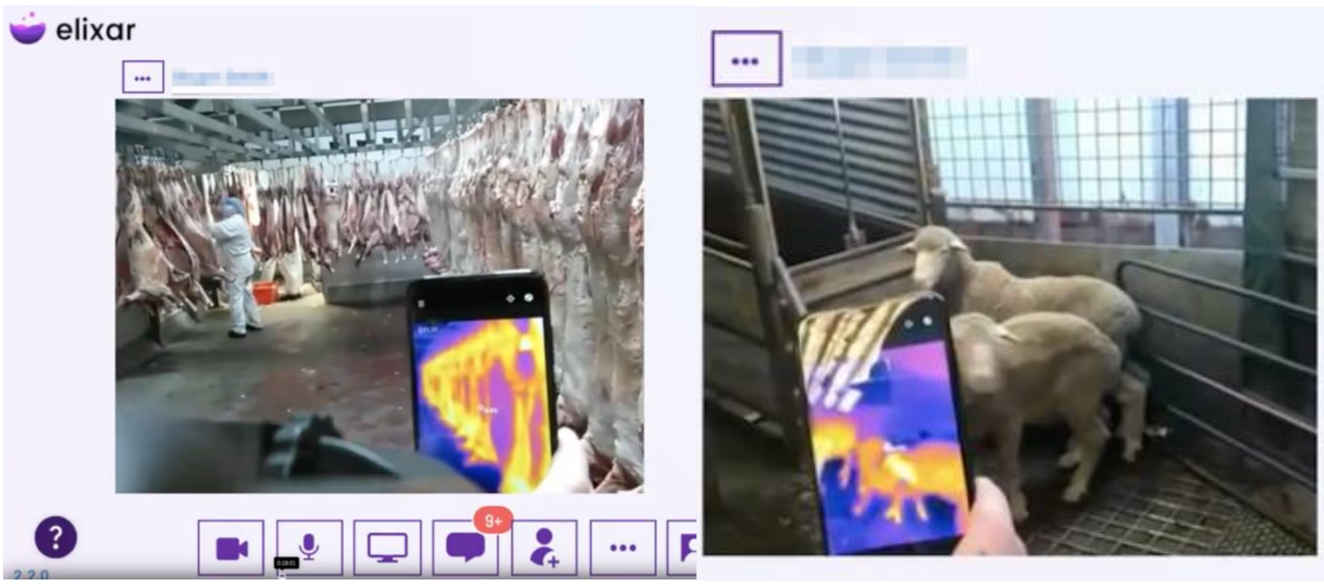


Figure 20: Thermal Camera Inspection Chiller and Live Animal Inspection

Technology User Testing and Observations:

Each major feature that is designed and developed into the Elixar platform is user-tested with internally sourced and project participants. Results from this user test helped to highlight areas for improvement and confirmation of value/use cases for the features. Data collected during user testing included recorded behavioural observation, post activity survey and interview. Recorded video and interviews was qualitatively analysed using thematic for key usability problem areas to be addressed in future software updated. Participants are asked to join a session and instructed to complete tasks related to using either the Elixar website or smart glasses app. After the session, participants are asked a series of questions about their experience, as well as being provided a survey to complete. The session is also video recorded and studied using behavioural observation methods to extract qualitative from their actions and utterances. These results are formulated into a usability test report for review by the software development team.

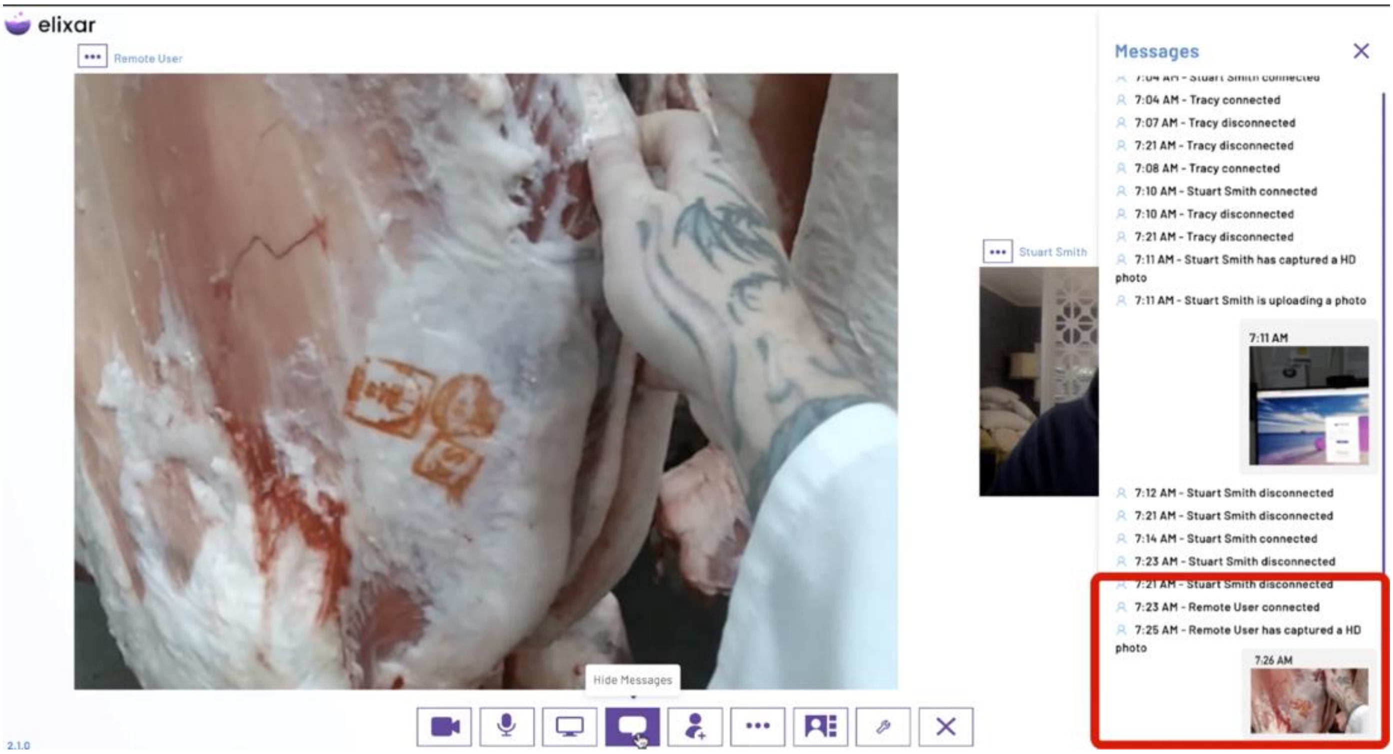


Figure 21: Remote Audit – Photo Capture User Test with Project Participant

Benefits of Remote Auditing

When asked, most participants responded that they think remote inspections would benefit their business. When delving deeper, key benefits were raised such as:

- **Cost saving:** (*QA2) "Time saving, accuracy of reporting (some issues are better shown through visuals), "saving money on plant audits.", (QA4) "Saving a lot of money and time."*
- **Ongoing Benefit:** *(QA5) "Once the technology can be properly used throughout the plant and the user is familiar with all the settings and parameters the possibilities could be endless."*
- **De-Risks Inspections:** *(AUDITOR1) "Auditor safety",* (QA*3) "Less visitors in pandemic times."*
- **Other Use Cases:** (QA3) "*Alternative verification tool when DAWE is short staffed." And "possible ante mortem tool if accepted by o/s regulators."*

Reducing the cost of compliance

When asked, most participants responded that they agree that regular use of remote inspections will lower the cost of compliance and reduce the number of authorised visitors onsite. Many processor operators highlighted that the cost of compliance is high due to many factors e.g. *(QA4) "We are located in a regional area and are also an international exporter. Travel costs for auditors are considerable and currently unavoidable"*

When asking for further detail on this, one QA manager stated *"The cost of compliance audits, and the frequency of them has long been an issue for the meat industry. Taking into account the extra time that they take away from the day to day running and monitoring of meat plants, the ability to remote audit puts time and cost effectiveness back into the hands of individual plants, and the meat industry as a whole."* For some however, they had concerns that remote inspections could end up costing more. As one auditor put it *"It is possible, but not always the case. It could cost more time in some cases"*. The research team did observe this in situation when audit participants were not prepared or trained to conduct remote inspections.

COVID Normal

Other comments made which highlighted some of the benefits to remote inspection during a global pandemic e.g. *(QA2) "Covid has had a big impact, we're not allowing any auditors or visitors on site at all. Even if we could there ae some auditors who can't actually come to us because they are in lock down."* As one QA manager put it *"Definitely a tool to be utilised in the future. With the uncertainty of covid or any other such infection that may come about this technology can be a way of still remaining compliant with program requirements, audits.."*

Negatives of Remote Auditing

When asking participants what negatives they saw when conducting remote inspections, some key themes emerged such as:

Training
There is a need for training and preparedness *(AUDITOR1) "Training for use by multiple appropriate persons per site."* This was observed during situations where audits were arranged but either QA staff or auditor may not be prepared for the situation i.e. missing headphones, devices not charged or not trained to use the device..

Lack of Presence:
A concern heard from multiple individuals was that there would be a lack of presence, immersion, peripheral vision and loss of other senses when conducting a remote inspection. As one QA manager put it *"Video streaming does not show the full experience of being onsite - no way to experience the full organoleptic ambience such as smell, which is a good indicator of hygiene".* In some cases, there were concerns that it may be easy for individuals wearing smart glasses to intentionally not look at certain areas. As one auditor put it *"Intentional restriction of auditors view."*

Cyber Security and Privacy:
It wasn't often mentioned during many of the touchpoints the research team had with participant organisations, however some did raise the issue of security of the footage. As one plant operator put it *"Security of footage. No controls around the intrusive nature and therefore opens establishments to reputational damage. Media has a history of taking the worst 10 seconds footage in 10 hours of collection to create a dramatic headline story. Users are exposing themselves to a vulnerability they would not through traditional methods.".* Some participants also raised concerns over how regulators and audit customers may come to re-used footage collected from onsite e.g. *(QA3) "We are hesitant about how regulators/customers secure footage."*

Additional to the security of footage is the privacy of individuals who may be intentionally or un-intentionally filmed during a remote inspection e.g. (QA5) " … staff and operators not feeling comfortable being recorded or on camera as it travels around the floor. I believe introducing this technology to workers and advising them what the glasses do and their purpose may give a better comprehension for the workers to welcome these new innovations."

Regulator Adoption:
Issues around regulators speed to adopt remote auditing was a concern raised by some e.g. *(QA4) "adoption by regulatory authorities of new technologies is always a bloated and slow process. It seems unlikely that will change at any point in the near future.".* It should be noted that regulators were both active participants and observers to this research project. And that their feedback and input was cautious yet positive in supporting the possibility for some inspections in the future to be accepted via remote methods. In fact, Department of Ag audits are often partially conducted remotely i.e. desk / documentation audit component has been completed entirely remotely during the COVID pandemic.

Part 4: Remote Auditing using smart glasses (Continued Rollout)

Initial needs analysis was conducted which included research interviews with participating organisations QA staff, documentation collection and literature reviews. This investigation aimed to understand the business challenges around compliance inspection and get a better picture of auditor / QA needs. Challenges identified were:

- Preparing for audits is time-consuming
- IT problems can be massive roadblocks
- Audits are time-consuming
- Audits (visual inspection tasks) are duplicated across many different audits e.g. Halal, EMSAP and AUS-MEAT audit all often ask the same or similar questions.
- Communication can be challenging in a noisy environment and with poor connections.
- Hard to plan an audit.
- Sometimes can't talk at all and need other forms of remote communication.
- Need to trust the system they are using.
- Needs a champion and outside influence need to use technology to ensure technology is not forgotten about.

The investigation led to the following solution needs being identified:

- Implement measures to quickly prepare for remote audit
- Clear communication and ownership of IT checks
- Find opportunities to reduce the number of audits by combining multiple auditors in the one call.
- Ensure good quality earphones are used during the remote audit
- Remote inspection participants agree on pre-defined walk path before inspection begins
- Use text messaging to communicate
- Improve just in time help tools e.g. guides and videos

The proposed solution to these needs are a series of improved process and tools provided to all participants of a remote inspection session. This includes:

- **Technology Readiness:** IT and WiFi checks completed before attempting a remote inspection
- **Pre-Planning:** Quick Pre-Start checks to complete before attempting a remote inspection
- **Help and Support:** Web based knowledge centre and instructional videos available anytime.
- **Contact and Support:** Bi-Weekly catchup call with participant representative to help facilitate remote inspections and audits
- **New Inspection Types:** Supporting the running of remote training, maintenance, and ante Mortem inspections

Technology Readiness (IT and WiFi checks):

It was found over the course of the project that firewall whitelisting and WiFi access point coverage were the two main limiting factors to the success of a remote inspection. To mitigate this issue from occurring un-expectedly the research team developed an IT whitelist checklist. This checklist could be provided to either internal or 3rd party IT teams servicing meat processors to help identify WiFi blackspots and overcome IP whitelisting issues (Figure 14).

Using this checklist would often identify WiFi blackspot issues which instigated a thorough review of network infrastructure in facilities. On more than one occasion the research team had to discontinue trials due to insufficient network connectivity and/or unable to improve WiFi coverage within the project timeline.

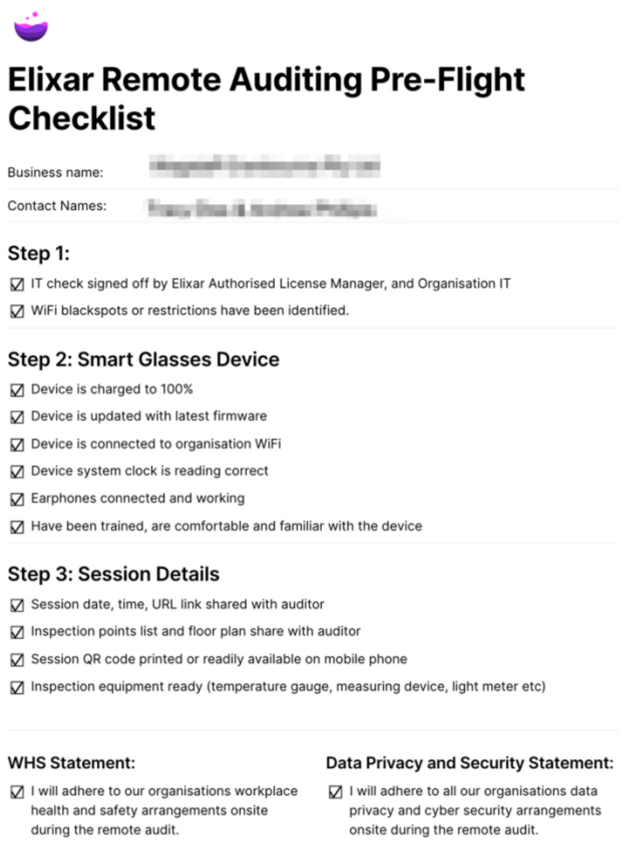
Common WiFi blackspots for almost all processors was the Chiller. As one QA manager put it *"I've done a walkthrough of the production areas today and tested out the Wi-Fi ranges and speeds, the slaughter floor, boning room and loadouts (old and new) have full coverage and decent speeds so no issues there. Only dead spots I could find were outside at the yards, and in the body chiller between the slaughter floor and the boning room, not sure if they'll need to go there for the audit but we can work something out if need be."*

Pre-Planning

The research team observed trial inspections to gain a more complete picture of what leads to a successful inspection. It was revealed that preparedness is vitally important to success. Common issues observed were:

- Device Battery not charged
- WiFi firewall changed
- Limited or no training using the Smart Glasses device
- Limited or no training conducting a remote inspection
- Poor planning before inspection i.e. agreed agenda and inspection route
- Poor communication around scheduling the Audit time/day

In order to assist participants to become better prepared and succeed, a number of preparatory steps were suggested to all participating organisations see (Figure 22). When all of these steps were followed by participants, it was observed that remote inspections would be highly successful. And in cases where it was clear some or all steps were not followed, it often led to a failed or aborted inspection.



Elixar Remote Auditing Pre-Flight Checklist

Business name: [illegible]

Contact Names: [illegible]

Step 1:

- ☑ IT check signed off by Elixar Authorised License Manager, and Organisation IT
- ☑ WiFi blackspots or restrictions have been identified.

Step 2: Smart Glasses Device

- ☑ Device is charged to 100%
- ☑ Device is updated with latest firmware
- ☑ Device is connected to organisation WiFi
- ☑ Device system clock is reading correct
- ☑ Earphones connected and working
- ☑ Have been trained, are comfortable and familiar with the device

Step 3: Session Details

- ☑ Session date, time, URL link shared with auditor
- ☑ Inspection points list and floor plan share with auditor
- ☑ Session QR code printed or readily available on mobile phone
- ☑ Inspection equipment ready (temperature gauge, measuring device, light meter etc)

WHS Statement:

- ☑ I will adhere to our organisations workplace health and safety arrangements onsite during the remote audit.

Data Privacy and Security Statement:

- ☑ I will adhere to all our organisations data privacy and cyber security arrangements onsite during the remote audit.

Figure 22: Elixar Pre-Flight Checklist used to prepare for a remote inspection

Help and Support

A web based knowledge base was setup that provides users just in time information and training on how to use the remote inspection software system. Included in this documentation were short (30-60second) instructional videos that demonstrate how to perform certain actions e.g. how to connect to WiFi. The research team also provided remote training sessions for all key project champions within an organisation. In some instances, the research team was also on hand to quickly provide over the phone support to participant organisations who may be about to conduct or in the middle of an audit but had a technical difficulty. In almost all of these situations, the research team was able to quickly resolve the issue. In cases where the research team couldn't immediately resolve an issue, it was found certain pre-planning steps were not fulfilled by the participant organisation e.g. WiFi check or device was fully charged.

Contact and Support

Two-week catchup calls were scheduled with all project participants. These 30 to 60-minute discussions via phone call or video chat aimed to:

- Understand their business challenges, focusing on food safety, inspection and compliance.
- Communicate how the current projects are going and gather feedback on early ideas.
- Communicate how to continue to pilot the Augmented Reality remote inspections in their business.
- Begin to understand the technology readiness of their business to support remote inspections
- Deeply understand different areas of the business that could benefit from remote inspection or automated camera systems.

Remote Audits

A key objective of this project part was to answer *"Can I complete a full remote audit in real time the processing plant?".* Progress towards supporting organisations to complete remote inspections can be found in (Table 11). In summary, many real remote audits were conducted during the project. In some cases, the research team was invited to observe the session see (Figure 23).

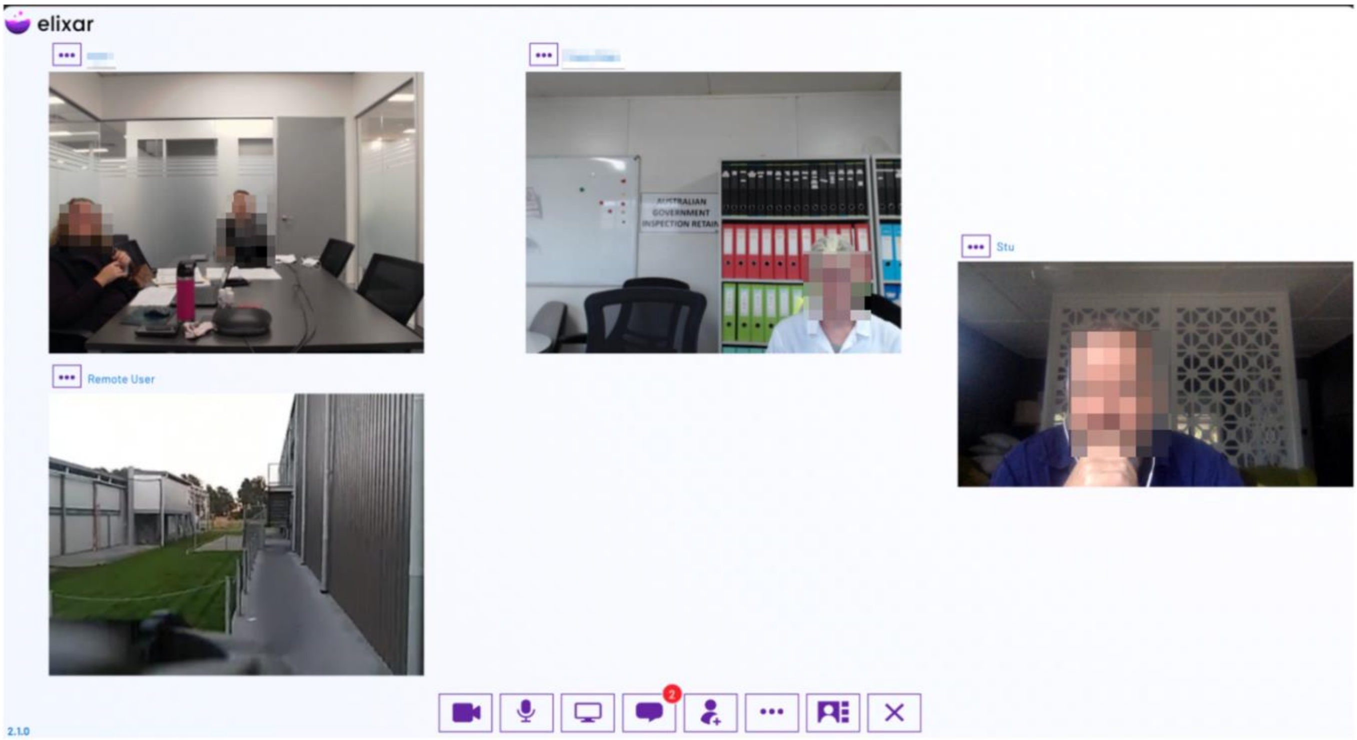
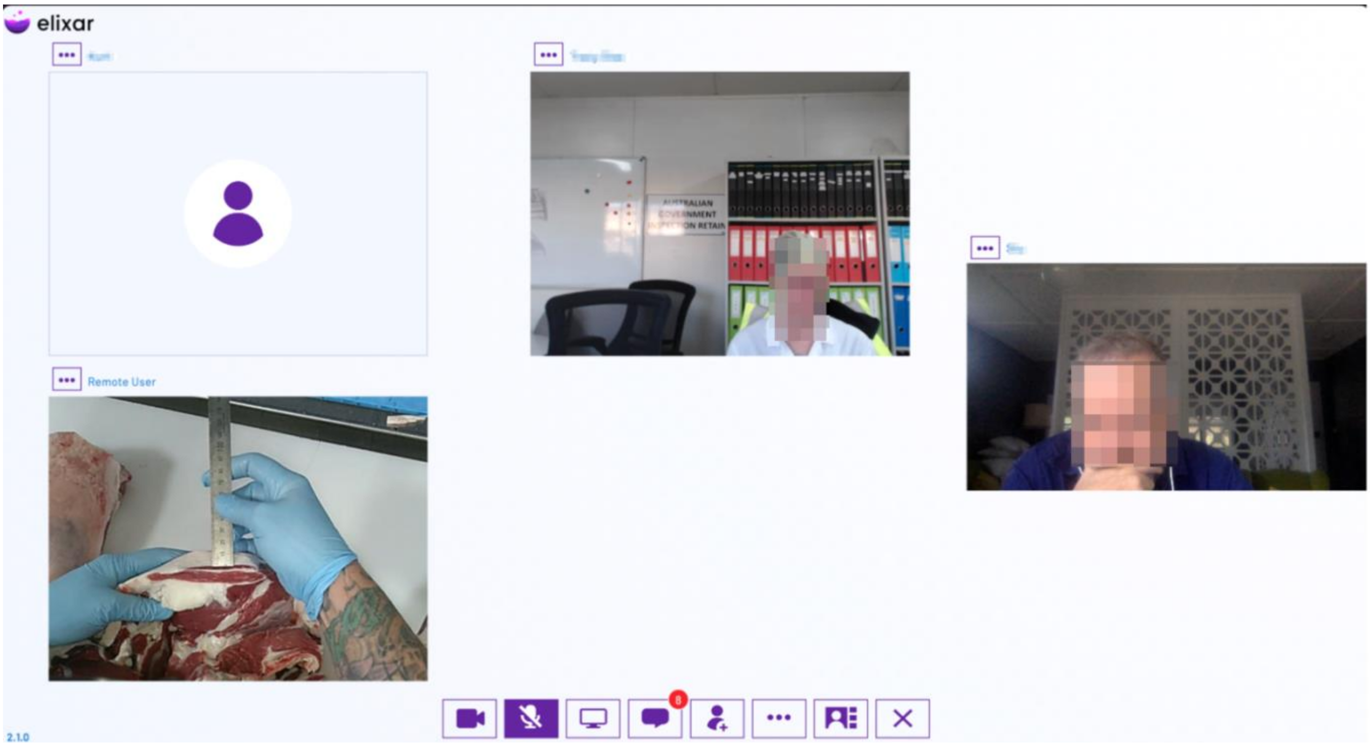


Figure 23: Elixar Remote Audit session connecting two QLD auditors, 2x VIC based QA managers, and NSW based research team member



The following table (Table 11) summarises the 313 Elixar sessions that have been generated by eleven unique meat processors and four agencies since 31 March 2020. Sessions have been classified according to the descriptive information entered by session creators. As can be seen, the largest proportion of sessions (53%) involved initial training and testing of Elixar and the RealWear system. Full audits are defined as those where the session creator entered details into the Elixar session management portal which indicated an audit activity that was not otherwise classified as a trial or test audit. Confirmation of audit status through follow up by phone/email with the relevant organisation.

Meat processors and agencies		**Session Type**							
ID Number	Elixar sessions created	Elixar Training/testing	Preflight check	Trial Audit	Full audit	Internal comms	Staff training	Maintenance	Demonstration
1	1	1							
2	8	8							
3	2	2							
4	16	8	3	2	1			2	
5	1	1							
6	37	16		4	3	8	6		
7	45	23	2	9	3	6			2
8	68	34	4	9	7	5	3	1	5
9	6	6							
10	22	12				10			
11	29	16	1	2	3	1		3	3
12	14	12	2						
13	46	12	6		8	8		11	1
14	10	8		1	1				
15	8	8							
Total sessions	**313**	**167**	**18**	**27**	**26**	**38**	**9**	**17**	**11**

Table 11: Project Remote Inspections Observed

Of the sessions classified as “full audit”, 2 were with Aus-Meat and 5 with halal certification agencies (AHDAA, HCA). Other full audits were classified as conducted with customers or as regular equipment audits not classified as maintenance. At this point, IT whitelisting issues prevent full audits being conducted with DAWE. At least one full audit was scheduled and attempted with DAWE however whitelisting issues with the Department PC prevented the remote audit from continuing. DAWE trial audits have been possible when inspectors use their own PC/laptop and home WiFi network to connect to an Elixar session.

As recently as 26th October a new meat processor has received a RealWear headset and is now in the process of training staff to undertake remote audits. This company has expressed an interest in using Elixar to facilitate virtual tours of their processing operations for market access to Indonesia. We have also initiated trial of audits with the Coles suppler audit team. As with DAWE, we initially faced IT whitelisting issues which are in the process of being resolved. We expect to conduct full remote audits with the Coles team before the end of 2021.

New Inspection Types

Of interest is the fact that a number of processing organisations have started to explore use of our remote audit tool for more than audit-related activities and have used Elixar for internal communications, staff training maintenance and equipment inspections with equipment manufacturers as well as providing virtual plant walk throughs for customers and others. In addition to these, the research team has explored with project participants other opportunities to use remote inspection technologies for audits. It was found outside of the DAWE, AUS-MEAT and HALAL audits, Environmental, and workplace health and safety audits could also benefit from using this technology. In-fact, auditing both internal and 3rd party is potentially occurring to some degree every day of a month (Figure 24), thus it is proposed that remote inspection solutions can be continuously used to reduce the need to travel, increase the level of surveillance and improve responsiveness to critical incidents.

Figure 24: Opportunity to use remote inspection technologies every day of the month

In the following we list a number of the alternate use-cases that we have observed,

Maintenance

The research team encountered a couple of processors exploring alternate uses for remote inspection and auditing tools. In particular, remote inspection had been used for remote machinery and equipment inspection and maintenance. As an example, one of the processors we work with in Victoria has conducted a number of remote inspections of their vacuum sealing equipment by the equipment engineers based in Germany.

Another processor in NSW has recently conducted a remote equipment inspection with an equipment supplier based in France. The particular piece of equipment inspected was a beef-bone separator.

This remote inspection project involved a couple of stages:

1. introduction and training on use of Elixar for French company
2. Training maintenance staff at processor on effective use of our remote inspection tool
3. Maintenance staff set up and forwarded session details to equipment manufacturer and arranged dates of inspection
4. First inspection of the machine in its disassembled state
5. Follow up inspection during a production run. (Figure 25)

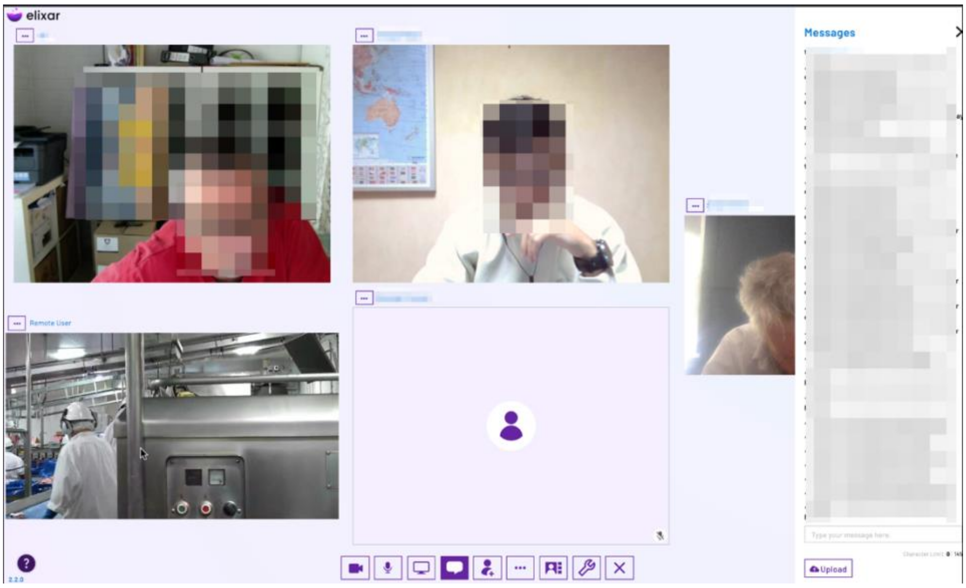


Figure 25: Elixar Remote Maintenance connecting foreign supplier (France), NSW Processor, QLD supplier

During the disassembled inspection, the equipment manufacturer shared a screen of parts and asked the processor maintenance worker to show and measure specific components, for example the inner diameter of a grinding plate (Figure 26). Full inspection of all components in their static state was possible given the quality of the video feed (Figure 27). Feedback from the remote engineer was that he was pleased with the ability to communicate directly with the on-plant maintenance worker and found the ability to share schematic diagrams to direct and guide the maintenance worker to be very useful.

During the production run, while the video feed quality was sufficient for inspection of bone inputs into the machinery, it was noted that improved video resolution would be required for some finer analysis of waste product output. The waste product conveyor speed was sufficiently high that the video feed was too blurred for adequate inspection.

Note that the same processor involved in the remote inspection of the French beef-bone separator is soon to use our remote inspection and auditing tool for commissioning of a new Dissolved Air Flotation (DAF) system. There are a number of different contractors involved in the commissioning of this significant infrastructure including businesses based in New Zealand and Melbourne. Covid travel restrictions have prevented staff from these companies attending the NSW site to conduct commissioning in-person. We have therefore completed initial training with these companies and are awaiting a date for the remote commission activity.

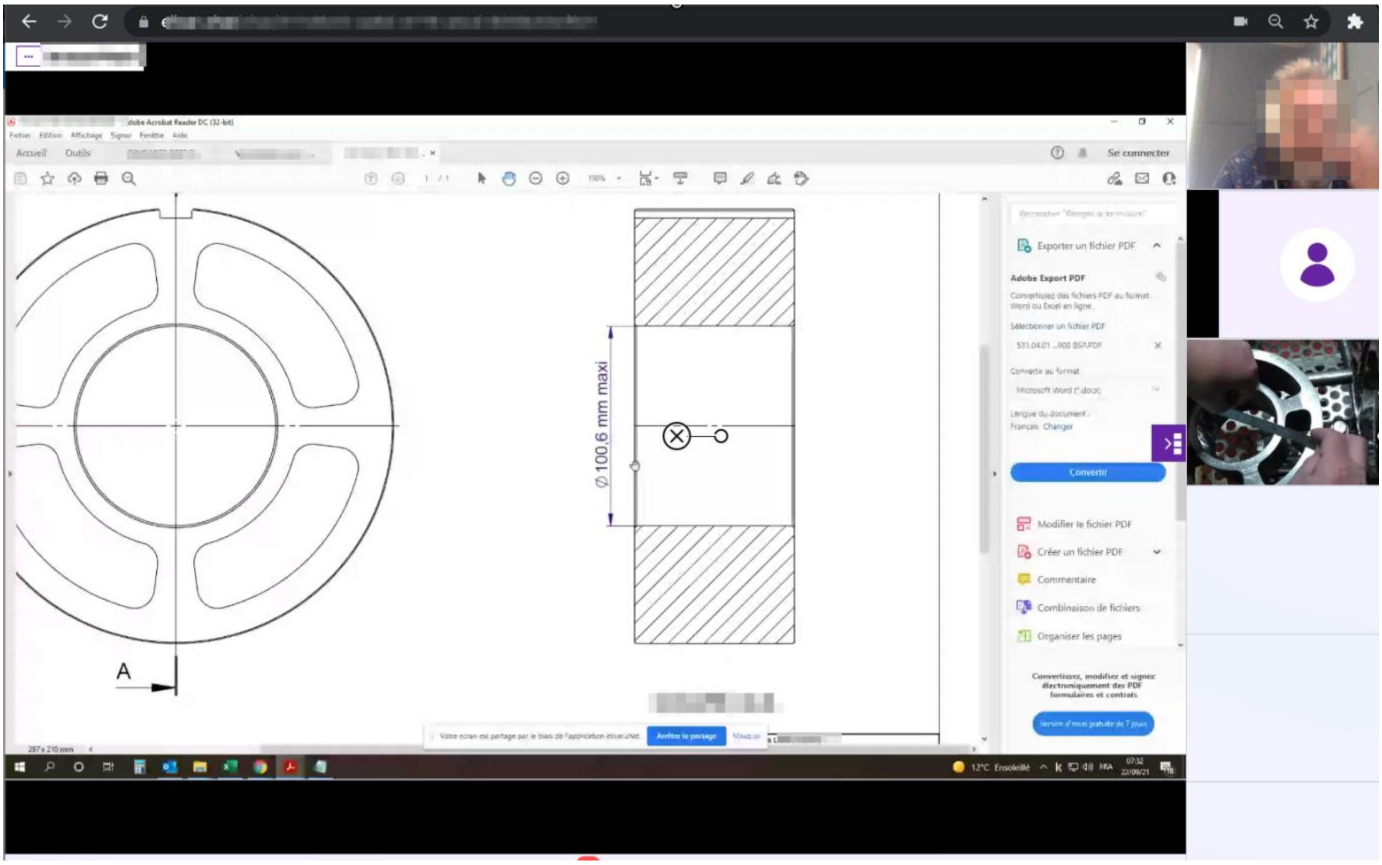


Figure 26: Elixar Remote Maintenance session, sharing equipment schematics for engineering check

Figure 27: Elixar remote maintenance session, checking equipment internals in NSW processor

Training

At commencement of the first trials, we began to consider the application of remote technologies with training and mentoring across the sector. While not the initial focus of the remote inspection project- it became very clear that the teams we were working with also began to think about how they could use the technology to capture some of the amazing experience out there in their teams. Our first demonstrated opportunity came from the Fletchers International Plant in Dubbo NSW.

The local RTO (Registered Training Organisation) had unfortunately collapsed during COVID and the Fletcher team had to reach out to TAFE Queensland for assistance with their AAO (Australian Authorised Officer) training- this would prove to be a more costly endeavour due to distance as the trainers were in Brisbane Qld. The site champion however saw this as an opportunity to introduce the device and platform to TAFE Qld and offer them the opportunity to do a remote 3rd person assessment on their site trainee. The RTO was so impressed they signed off the trainee and began to negotiate with the team to utilise this technology as a part of their assessment process in the future. With future focus here and just as a single example: it is hoped that the device will be able to be worn be experienced team members that may be reaching retirement to directly share their expertise and techniques to groups of trainees remotely so they can benefit and learn directly from some very important mentors.

(QA2) *"It is going to be a good training tool. A lot of our training is through printed or PowerPoint. Because we have a lot of non-English speaking workers, being able to capture video information though the headset."*

(QA5) *"This can then be utilised for training purposes.."*

(QA2) "*For a lot of jobs there is no way that you could stand close enough to see what needs to be done but with the zoom feature in Elixar we can give trainees close up view of the task."*

(QA5): "We have talked about using it for training, as in taking videos of various tasks being performed and using them as an adjunct to the written work instructions. Much easier for non-English speaking folks, and those with poor literacy skills. Also, a lot of jobs are more easily taught if the trainee can actually see what to do, rather than written or verbal explanation. You could then take footage of the trainee performing the task competently and use it as part of the sign off for that task."

Animal Welfare

We have worked closely with one processor who has identified a use case for our remote audit and inspection tool for conducting remote health and welfare assessments of animals in lairage. This processor has been particularly proactive and forward leaning in their uptake and use of Elixar.

QAM: *"Animal welfare is another area we are considering, there has been talk of using it for reporting an emergency animal disease. So you could hook into a Government vet to say to them, this is what we found and they can see through your eyes what you're actually encountering. This is important for some of these exotic animal diseases, time is critical."*

The QA manager at this processor approached the on plant vet (OPV) to introduce them to the Elixar tool and engage them in conducting a remote ante-mortem inspection. The OPV, QA manager and QA assistant conducted a remote health and welfare inspection in September which involved an hour-long walk through the holding pens for a consignment of sheep (Figure 28). Feedback from the QAM and OPV below.

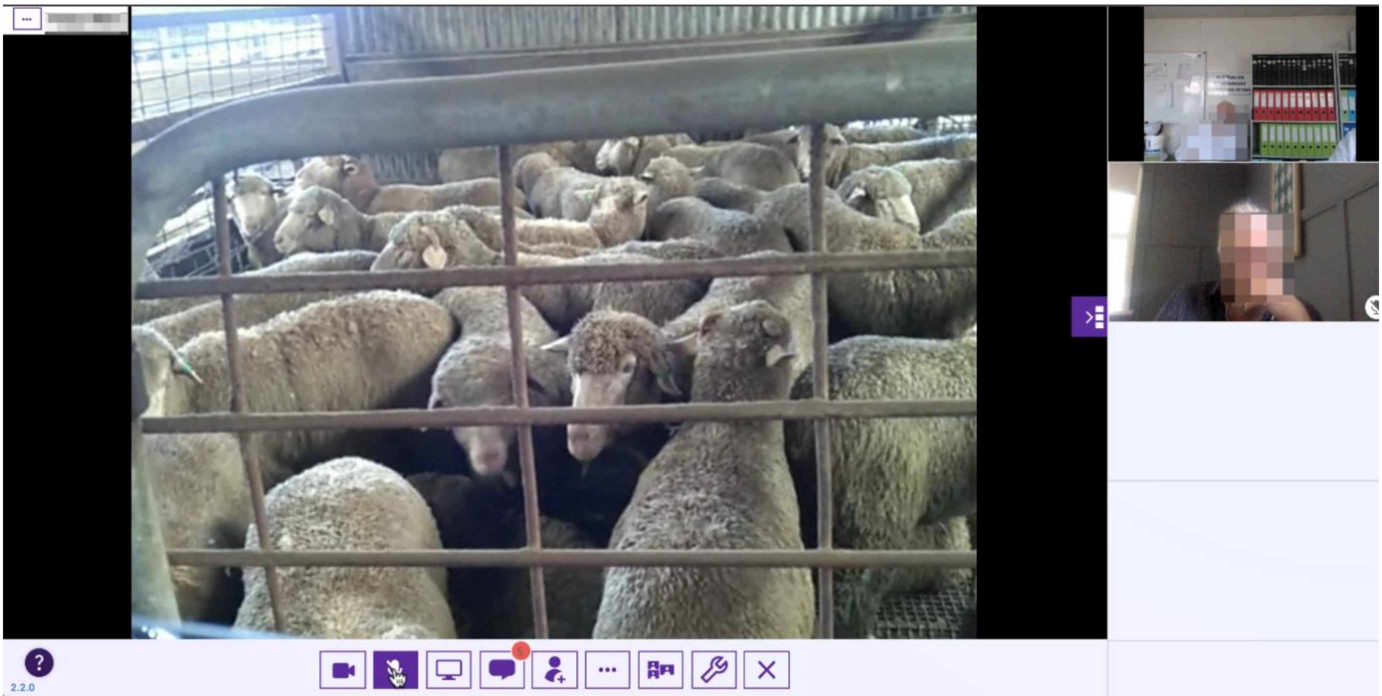


Figure 28: Elixar remote Animal Health inspection with remotely located OPV

QAM: *"Our OPV might have a breakdown on his way to work and we'd need to call in a replacement vet who may not be able to get here in time" Even if the FSMA could do the job, it would be better to have the OPV engage in inspection even when they can't make it, for whatever reason"*

OPV: *"I agree, this can be really useful for emergency situations. For example in country towns it could be floods that prevent an OPV getting to a site. Once you get a foot in the door as an emergency backup it (Elixar) could be extended"*

QAM: *"in the case of exotic disease, even if our own OPV is here they could call in an exotic disease specialist and ell them, this is what we are seeing"*

OPV: *"it would be extremely useful for that"*

Customer Walkthrough
Meat processors have commenced internally trialling the smart technologies to conduct remote site visits for current and potential clientele. An example was provided by one partner provider that each and every year they experience site visits (pre-COVID) of up to 850 individuals conducting tours of the facility. The costs for these "site tours" can vary however the preparation for these events is incredibly time consuming and laborious. WHS aspects, group sizes, PPE and many other aspects need to be considered for every occurrence. We have had 2 sites confirm now that they have conducted very successful "virtual tours", the first being with a Korean importer of beef and the second being a U.S partner and importer. Both occasions yielded positive results and some very impressed clients. The U.S client was so impressed with the platform there may be an opportunity to demonstrate directly in the near future.
(QA5) *"any other such activity where visitors or auditors cannot come on site. This includes International visitors wanting to see the plant for potential business ventures but cannot fly due to restrictions."*

(QA2) *"Another thing that we can see the use of Elixar is for customer inspection. Say we have a customer in Japan and they are interested in buying a container load of boneless legs or racks and they want to see what the product looks like; well it is one thing to see a picture on a spec sheet but with the glasses you can show them and rotate the cut. Show it before the packaging, show the packaging, show the processes and this gives the customers more insight into what you're actually offering and the processes and hygiene around it as well.*

(QA2) *"You could show in real time a ruler measuring the fat depth or the cut specs.*

Costs and ROI

A sample ROI for a small to medium-sized facility is based on one audit company- for example, Aus-Meat conducting 4 x on-site audits per year. The average for this site is an audit chargeback to the plant of $5,000 per visit which includes several factors including flights, accommodation and other charges for the duration of the audit. To create an ROI for the purchase of one device kit- we will have to reduce the onsite visits from auditors by just 1.5 per annum (if based on only one audit body). A successful remote inspection or audit will reduce the costs of between $1000 and $2000 per visit. If the onsite visits could be reduced by one per year for just DAWE, Aus-Meat and multiple Halal agencies - the device has generated an ROI to cover purchase and costs related to a service like remote inspection software (Elixar) for the period. As we progressed through this trial period, however- we are seeing that our industry partners are not only utilising the Elixar platform and a device simply for one or two remote audits per year, they are additionally reducing costs to their business through other remote interventions including (not limited to): training, international virtual tours, local and international equipment support and remote professional interventions, for example, ante-mortem inspection support. Compounding this return on investment is the option to conduct multiple audits within one session i.e. multiple audit organisations join a remote call. This was trialled during the project with reasonable success. If adopted as an audit model could significantly reduce the cost of compliance for the industry.

This includes a device with 2 x years warranty, hard case and accessories to create a delivered product that is ready to use when received and the instructions followed. While a preferred device is currently being used- there are multiple options with varying pricing currently available.
The selected device has been very industry-specific- robust, simple and economically viable. A clear point of difference here has been the battery life of the device- up to 5 x hours which continues to be a standout feature. For almost 30 devices currently being used for this and other projects- we have only replaced one battery across all of these devices in the last 16 months.

Part 5:Cloud-based data centre for the Red-Meat Industry

Collection and storage of sensitive visual data from a meat processing plant have traditionally been kept only onsite with "air gap" security i.e. not connected to the internet. Whilst this method offers a very secure way to store sensitive material, it makes it hard for that material to be shared with trusted 3rd parties. There is a huge amount of visual data that could be utilized to a) complete remote audits, b) share with customers, c) improve research e.g. training machine learning object detection models. Additionally, concerns have been raised by the industry around the new remote inspection technologies. Key concerns raised have ranged from the vague to the specific. For example:

- How secure is this remote streaming platform?
- Is the image and video data encrypted?
- How can foreign actors attack this network?
- Does your solution use 2-Factor Authentication?
- How do we ensure video data is not tampered with after recording?

The first four of these questions is relatively easy to answer and in summary, the remote inspection software utilised in this project (Elixar) meets these requirements. The last question "How do we ensure video data is not tampered with after recording?" is a little harder to demonstrate compliance. This is a common issue faced by almost all cloud based video streaming and data collection services. To address this in particular, a "Trusted Video" security architecture was designed and developed during this project see (Figure 29). This work was a collaboration with Bondi Labs and the University of Queensland's cyber security research group. The trusted video work aims to develop an innovative method to digitally sign video as its captured, allowing any un-trusted/signed video to be easy to detect.

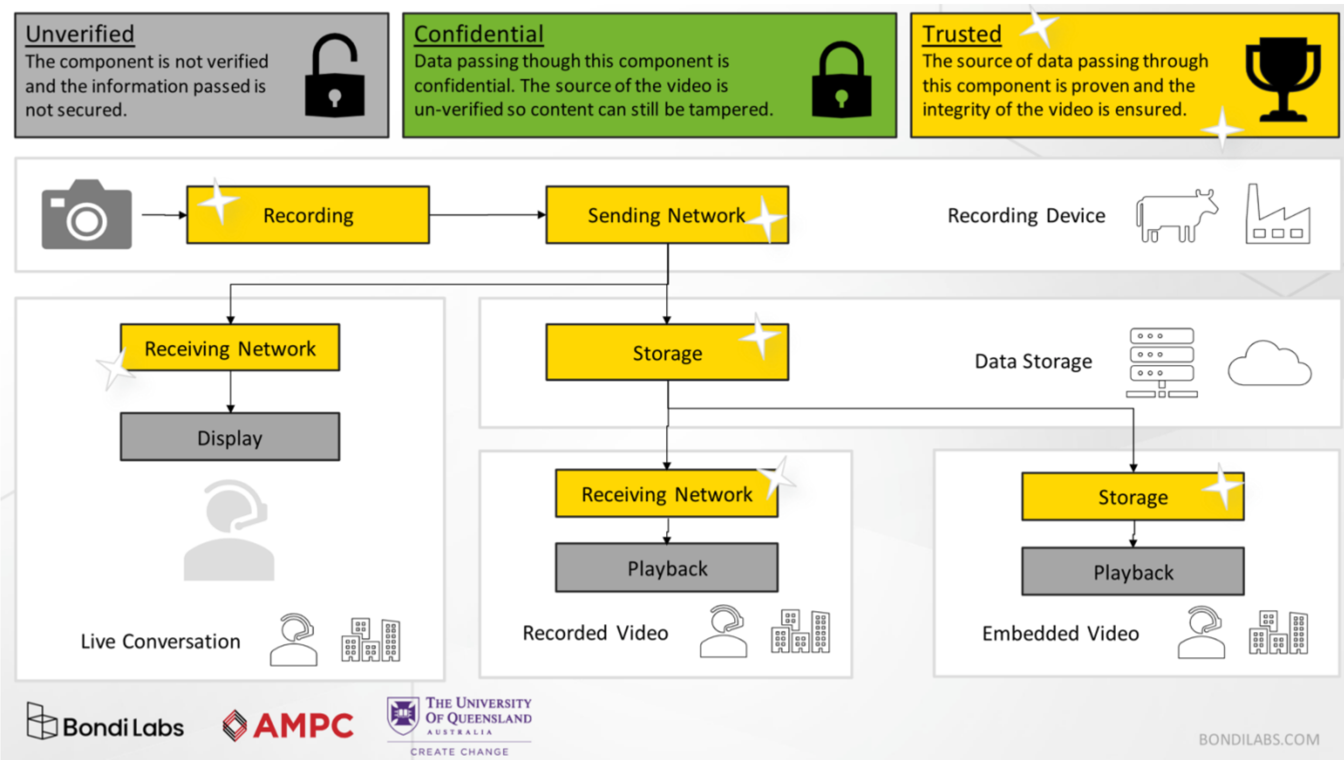


Figure 29: Trusted Video Cyber Security Architecture

It was hypothesised that on modern faster computers the Trusted video solution shouldn't cause any noticeable visual, audio, or frame reduction in video streaming. Additionally, it was expected that lower performing computers would potentially suffer from lagging video frames/audio and poor performance.

Observation of the solution running across three different computer spec, found the following.

- High-end systems see no noticeable difference between trusted and untrusted streams. With enough system resources the overheads are not significant enough to impact the stream.
- Mid-range systems see small amounts of delay worsening as more users enable trusted video. The delay causes the video and audio to become out of sync.
- Low-end systems experience significant interruptions with the video stream.

For our evaluation the research team split the trusted video into 3 different parts. Hashing, Signing, Verification. Our signatures operate on hashes of data rather than the full video frames. The first part of timing is calculating a cryptographic hash. This processes each frame and takes a variable amount of time depending on the amount of data being hashed. Cryptographic hashes are optimised for high performance to calculate the content of files so the total time taken by this hashing is negligible.

The signing takes the hash and combines it with the private key to create a signature. This process needs to be done for each frame with our current solution, but the same hashed content is sent to each user, so this scales well with the number of users in a call. The verification takes a signature, a public key, and a hash and validates that the signature was the hash signed with the corresponding private key. This takes the longest time of each of the three parts and needs to be done for each frame being verified. This is where we have encountered scaling problems as lower-end systems struggle to verify multiple incoming streams. User testing found video feeds for users on high end PC's were indistinguishable thus the solution effective in quietly running behind the scenes to ensure the connections are secure and trusted.

6.0 Discussion

The following discussion section will aim to answer each relevant research questions for each project part.

Part 1: Box Labelling Issues Discussion:

RQ1: Can an AI based camera detect common meat cuts are in a carton?

Yes: Deep learning models developed were capable of accurately identifying one of six common meat cuts when presented Infront of a camera sensor. This outcome was limited to only six meat cuts due to the scope and complexity of collecting enough data for more meat cuts. The research team feels the deep learning model pipeline developed has laid the foundation to increase the number of meat cuts once enough data has been obtained and annotated. Therefore future work will look to detect more meat cuts approx. 20. To cover the most common meat cuts being exported for beef. It is expected that this will lead to a requirement of over 50,000 annotated meat cut images being sourced from 100's of hours of footage.

RQ2: Can an AI based camera count the amount of meat cuts in a carton?

Not Really: More specifically, the AI camera can detect the number of meat cuts placed on the top layer of the container. Therefore the research team can only proclaim the top layer of meat cuts can be counted and not any items hidden underneath.
Alternative solutions to do this task could be

1. Use Xray imaging to see through top layer of meat
2. Watch worker put meat into carton and count the pieces
3. Use combination of depth based estimation and weight sensors to estimate how many pieces of meat are placed into a carton.
4. Use RFID tagged meat labels to scan in and digitally show with a high degree of confidence the number of meat cuts placed into a carton.

RQ3: Can an AI based camera detect label non-compliance issues?

Yes: However this project only tested this in a limited capacity. The primary error to detect was the general acceptance of the meat type in a carton matches the type printed on a label. Other potential errors were also detectable such as missing key label information. What wasn't tested was the ability to detect language translation issues, or any of potential 60+ label errors that could occur. The research team is confident that the software system implemented can be expanded to support further label defects as some of the hardest computer vision challenges have been solved. Further research and development time would yield a result of all label defects being detected and reported. Furthermore, organisations who choose to use different label configurations could use this system as it is robust against the positioning of label features.

RQ4: Does highlighting these risks to onsite inspectors improve task accuracy, efficiency?

Un-Proven: The data required to answer this of this has not been collected yet. The box label verification rig was developed to progress the prototype to a state that could be tested in the field for short periods of time. Next steps for the rig will be to fabricate the rig using food safe materials such as stainless steel. And ensure the system is resistant to pressure washing.

The AI / CV detection software system is at a state where it can demonstrate all aspects of the system working together. Further improvement will be required to progress the software stack from a prototype to Minimum Viable Product (MVP) level of maturity. The same can be said for the web user interface which was designed to serve the needs of immediate field testing. Further usability testing will highlight areas for improvement. It is also planned to further integrate the existing Elixar remote inspection software solution into the web user interface for BLV. Future work will aim to address many of the found issues during initial field testing and ensure it is in an operational state that can start demonstrating its value to the meat processing industry.

RQ5: Where else in the business can this solution be used?

During the project, the research team engaged with a few meat processing organisations to identify where else computer vision could be used to detect non-compliance issues. Initial discussions were looking at Meat Hygiene Assessment i.e. carcass contaminant detection. Other ideas also steamed from the opportunity to use the meat ID system further up the chain to label application and when meat is placed into a box. Having a system to either instruct a new employee or verify the correct label has been placed or meat put into a box could been seen to be a valuable tool. A final idea was raised whereby computer vision technology is coupled with smart glasses i.e. automatically detect meat or label issues as you walk around a facility. As it stands, all three ideas would be initially pursued in future research projects if approved.

Part 2: Carcass Contamination Tool (ZT Ingesta, Faecal)

RQ1: Can an AI based camera detect visual carcass contamination indicators such as faecal matter, bile and milk?

This question still remains un-answered as no formal prototyping or evaluation was performed. Research investigations indicated that the use of a hyperspectral camera system coupled with Mask R-CNN deep learning could be a suitable approach to the detection of contaminants. This approach is alternative concept to other demonstrated technologies aiming to solve related issues i.e. detection of just faecal matter using single spectrum. The proposed hyperspectral approach would aim to be more inclusive of other contaminants.

It is noted that this project part was halted thus remaining a research inquiry, prototyping and testing was not thoroughly explored. The justification for this was due to the complexity and scope surrounding further research and development activities on this project. Additionally constraints also impacted and influenced this decision i.e. COVID lockdown limiting access to plant and hiring of hyperspectral equipment.

Further research works would aim to progress this project beyond just a research exploration, into a practical prototype experiment. This would include:

- Collecting sample data from the processing plant to train and test deep learning models
- Designing and building a hyperspectral camera rig and software system
- Testing the prototype both in lab and within a processing facility

Part 3: Remote Evidence Capture Tools

RQ1: What checklist audits could be supported using this tool?

It was found that almost all visual and behavioural parts to an audit could be conducted remotely. Any remaining audit tasks such as documentation checking can also be conducted remotely. This investigation only looked into how three common industry audits. There are hundreds more audits that should be analysed. For example other common audits to explore would be the Customer audit, Annual Organic, Annual Humane, and Annual SEDEX audit.

The research team analysed checklist examples provided by AUS-MEAT, AHDAA, and DAWE. It was found that around 71% of the audit could be completed via remote observation, with the remaining 29% completed by documentation checking. The DAWE EMSAP audit was also found to be supported in some part by the remote inspection. The analysis of the audit checklist found around 81% of the audit is documentation checking, with 19% potentially conducted using remote observation. The HALAL audit also had a majority share of visual observation approx. 81%, with the remaining 19% being document checks. From this limited analysis we can assume between 25% - 75% of an audit could be covered by using remote inspection technologies.

Next steps would be to collect more industry audit samples and have those be trialled/observed to see if there are any gaps or challenges in completing it remotely. Additionally, expanding out and offering the remote inspection solution (Smart Glasses and software) would help to re-enforce the benefits found to industry. The common pitfalls identified will also be investigated e.g. working to provide a solution to connect meat processors with internet service or network infrastructure providers. Improving the communication of cyber security, and working with regulators to formalise remote inspections as an auditing option.

RQ2: Can checklists be combined to improve efficiency?

Still to be Tested: It still remains hypothesised that combining audit checks into the one remote session can improve efficiency. At a theoretical level this approach seems sound. Initial analysis of combining at least three separate audits into the one checklist showed over half the audit would contain documentation checking. The remaining audit tasks can be done visually in different areas of a facility. The slaughter room, being one of the most heavily inspected areas. This can be due to the risk and number of critical control points found in this area.

If these three audits were to be combine into the one remote audit session alone, the audit time thus staffing cost could potentially be halved. Additionally, if you include the other common audits, the time yet again could potentially be lowered. We did not investigate any potential costs saved i.e. cost saving passed on by Auditors to meat processors. It is still early days, and further evidence of successful trials is required for audit agencies to better understand the cost saving incurred by conducting a remote audit

RQ3: Can I capture and share data whilst I perform tasks?

The research and development team created new tools to allow the sharing of sensitive image material from a smart glasses wearer to remote session participants. This feature allows meat processors the ability to control what data they capture and release for audit purposes. User testing of this added feature found users did find it a valuable tool, yet still had some questions around the security, privacy and where the data comes to live.
One key consideration raised by audit agencies was the freshness of the data i.e. needing to see data captured in real-time, rather than an image captured yesterday. This consideration was able to be met by ensuring images captured are uploaded instantly, and auditors can see when a user is about to capture an image.

It is hoped that users will continue to value having the ability to capture and share data with auditors. Previously some audit agencies did not feel the need to collect visual evidence for their own reporting needs. Now that these tools are available and secure, we hope to see that they can find value in have a visual piece of evidence to add into their audit report.

RQ4: Can larger groups of people join a call and contribute to an audit?

Still to be Tested: Early testing has demonstrated that Elixar remote inspection software can facilitate multi auditor calls. The successful audit of Wagstaff's, Gulf States Certification demonstrated that there is a viable solution to support this kind of larger audit taking place.

The primary limitation in conducting larger audits to date is that only 5 active participants can be in an Elixar call. It should be noted that other remote inspection software solutions may be able to overcome this limitation. The audit demonstrated was primarily focused on HALAL related requirements. Conducting a multi-agency call with six or more active participants i.e. separate web browser sessions is still to be tested. Early release feature of the Elixar software does now support this and will be utilised in ongoing user test sessions post this project.

RQ5: What other technology could support/enhance this solution?

Mobile and thermal vision camera devices were explored during this project. Feedback from these trials showed that there may be some opportunity. There may need to be further empirical testing and certification for the evidence to be used as an official instrument to measure temperature in a meat processing facility. The current use of vision based thermal camera is relatively untested in this industry thus can only be seen to be used as assistive tools e.g. quick scan of a room for heat to then use a certified temperature probe. Future work will aim to explore the use of new thermal camera hardware that has been designed to attach to the smart glasses devices.

Part 4: Remote Auditing using smart glasses (Continued Rollout)

RQ1: Can I complete a full remote audit in real time the processing plant?

Yes: This was demonstrated a few times during this project. Feedback from both QA managers and Auditors revealed, there is a desire to have an option to conduct a remote audit. However, some auditors expressed a preference for in-person, onsite audits.

The single most common concern for plants was limited or outdated connectivity. If the question here is “can I conduct a complete full remote audit” the simplest response is yes. The caveat here is: good connectivity, limited black spots within the plant and a quality team that has been trained in remote inspection.
A secondary limitation relates to internal communication within each site team. The research team found a trial site to have exceptional internal communication and it led to one of the first completed remote “live” audits. A successful result for a very strong and well-informed team. The other side to this is a team with limited internal communication and no dedicated “champion” of the trial. The result? Unsuccessful trial and a returned device.

Internally the research team has planned to bolster the level of participant engagement in the future. This is due to participant organisations needing a lot of support when first getting started. The refreshed approach will include a potential contractual styled initial onboarding, access to a dedicated site champion (or champions), clear options for connectivity and a roadmap towards very defined (and achievable) goals based on previous trials, successes and failures.

RQ2: What inspections in the business could be substituted or supported by remote inspection?

It has been proposed that 20% of existing audits could be replaced by remote inspection. In these cases, a meat processor may have already demonstrated good compliance behaviour previously with onsite audits. Their second audit for the year could be covered by a remote inspection instead.

This may not be the case for all meat processing organisations- in particular those who may not have done well in previous audits or who are limited by the availability of a good connection.
The usage cases here are not limited. The research team has had several discussions and requests for support around different types of audits. Further discussions have been had around more creative uses including internal site visits for a brand that has a site in NSW and another site in WA. They are already using the glasses and Elixar platform as an internal connectivity tool and have found it highly beneficial to alleviate the travel for management between the two sites.
This is a topic that has been discussed many times and could assist in performing some of the following examples:

- Workplace health and safety inspections, local, state or federally regulated
- Follow up of compliance requests or open notices- for example a notice to improve
- Plant or Equipment inspections or maintenance- local or international
- Trainee or apprentice assessments

The research team is not aware of all the various audit standards to make a call if every audit could potentially be conducted remotely. However we have worked within the framework of the DAWE (EMSAP), AUS-MEAT and AHDAA inspections in a remote capacity. The research team believes the remote inspection process, smart glasses and Elixar platform are able to deliver a high level of quality and assurance for the completion of a percentage of these audits.

RQ3: What changes to audit processes are required to conduct a remote inspection?

Working in partnership it will be important to understand how remote inspection works and how it will work within the parameters of regulatory bodies and end clients. The research team has completed some base work for example with the Halal community working between Australia, Dubai and Turkey. This work was to assist in the development of “acceptance standards” for the use of remote inspection tools to provide or participate in a remote inspection. Moving forward the research team may see new International Standards relating to remote technologies. However we will additionally need to be across relevant local, state and federal legislation and guidelines to ensure all work conducted is accepted and appropriate.

Preparedness tools for remote auditing is a significant outcome of this project. The research team implemented a rollout plan that aimed to prepare both meat processing QA staff and auditors to conduct remote inspections. In some cases, this plan was followed flawlessly. In others, some organisations struggled to remember to complete critical steps. The research team learned from these experiences and revised the rollout plan/strategy to include extra steps/checks i.e., pre-flight checklist, as well as closely monitoring all planned remote inspections.

Whilst there were a range of guidance support provided to all participants in conducting remote inspections, it comes down to the auditor and meat processing QA staff to be prepared and responsible to conduct the audit. This also includes allowing the two parties to agree on an audit date and time. The research team aimed to keep in regular contact with both groups to ensure support could be provided just in time. The Bondi Labs research support team worked hard to ensure that all stakeholders were not impacted negatively by this type of technology, had good communication, and aligned themselves to achieve organisational and industry outcomes.

It is expected that as the research team continues to support organisations to conduct remote inspections, they will learn and adapt remote auditing operating procedures. One concept that has been formulated is to certify all users who will conduct a remote inspection. This will provide a level of clarity and confidence that all individuals planning to participate are well trained, aware of the risks and can respond appropriately if there is a technology issue e.g., WiFi dropout.

RQ4: Where else in the business can this solution be used?

As touched upon earlier- there are multiple opportunities to utilise this type of technology across the industry. To date the research team has observed:

- Virtual tours
- Remote audits and ante-mortem inspections
- Combined audits between Australia, Dubai and Turkey
- Partner walkthroughs between Australia and the United States
- Equipment manufacturers checking their equipment on site in Australia while in the office in France
- Signing off trainees remotely and remote mentoring
- Remote fencing and property maintenance operations while on horseback
- Feedlot inspections and maintenance
- Animal welfare inspections
- Halal compliance checks

As with previous limitations, connectivity remains the largest concern. Outdoor work can usually be supported within most areas with 4g or 5g connectivity but internally the structure and connectivity play a major role. Additional to the actual connectivity concern is the cost and time to scope and set up. A final limitation here can be the dedication by the organisation to push forward and support with a solid team. Organisations need champions to embrace the opportunity, test it, provide feedback and ask for support until a process is perfected. This takes time, solid relationships and excellent communication.

Part 5:Cloud-based data centre for the Red-Meat Industry

RQ1: Can I securely record, transmit, store, and retrieve sensitive visual data collected from a meat processor in the cloud?

Yes: However this is a multipart question. The Elixar remote inspection solution does currently transmit video data using SSL encryption. Data is stored in encrypted cloud storage buckets and can only be retrieved via secure authorisation tokens linked to registered users. The main focus for this project part was to zero in on a critical future gap in security where if a piece of visual evidence were to leak out of the secure Elixar ecosystem, If this were to happen and that data is tampered with, is there a cost effective way to discover this fraud? The solution to this was called “Trusted Video”. Testing of this prototype solution did yield positive results as discussed below.

Future versions of the system will provide improved feedback to users. This feedback is best reflected when the system detects an “untrusted/signed” video stream. This can be seen in (Figure 30); whereby most trusted and signed users are confirmed by a green tick. Any untrusted video streams can be seen with a yellow warning icon next to their participant name. This signals to all users that the identity of the user who may be untrusted should be confirmed using other means. There is never 100% coverage or trust. Further work will continue to explore new ways to both fill security gaps and communicate this to the end user.

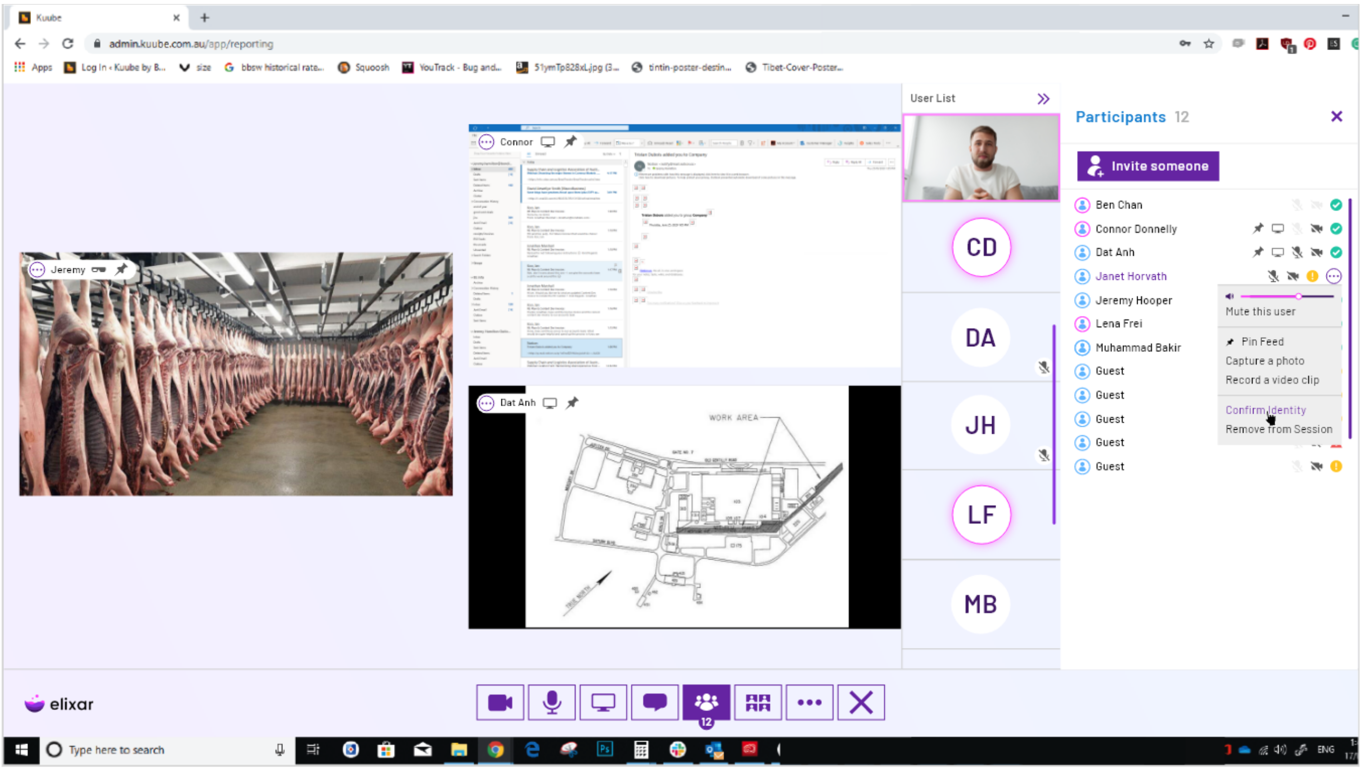


Figure 30: Future Version of Elixar with integration of Trusted Video

Camera Verification Proof of Concept Development

The camera verification component is a more cutting edge, complementary system to the Trusted video work. There are still some weak links in the trusted video architecture e.g. verification at the camera sensor level. This verification is rarely ever checked in technology solutions, especially video streaming solutions. The experimental work being performed in this project is using deep learning techniques to analyse the noise/signal patterns a camera sensor produces and use this noise pattern to further enhance the digital signing process performed in the trusted video work. This work is much more experimental, but early research experiments are proving successful. Further steps will be to apply this proof of concept in a software stack such as the Elixar remote inspection platform.

7.0 Conclusions / Recommendations

The project set out to investigate how remote real-time inspections and autonomous verification technologies can come to reduce the cost of compliance for the red meat processing industry. Key to this investigation was the research, design, development and testing of innovative technological solutions.

Continuous Verification

The project part explored the development of an innovative AI detection prototype capable of detecting non-compliance errors on export meat cartons and contaminants on carcasses. These two problem areas were investigated; however the carcass contamination part of the project was paused to refocus efforts on delivering a prototype solution for carton label verification.

The research team was able to successfully build an AI camera prototype solution and deploy it into a meat processing facility. The outcomes of this was that the prototype rig is capable of positioning a camera sensors at different angles near a conveyer belt, capturing data and storing it to either a local edge device or to the cloud. This hardware solution can be repurposed to perform other data collection, or camera capture tasks throughout a meat processing facility. The rig is planned to be improved to meet food safety and cleaning requirements in the future.

The AI software system running on the edge device and cloud architecture, is capable of detecting a small subset of vacuum wrapped beef cuts inside a carton, reading carton outer labels and determining if there are label inconsistencies. The project did not aim to detect all possible combinations of label issues, but there is a clear path to improve the system to account for these in the future. The software system is also designed to be somewhat module, so that different components could be re-used to solve other detection problems in a processing facility e.g. recognising meat cuts or labels further up and down the chain. The cloud dashboard was also designed to accept new camera systems or sensors which can relay vital detection information to QA staff.

It is recommended that the following occur to progress the project:

- Test the prototype rig out at other processing sites to further understand usefulness and usability
- Fabricate the camera rig to be food safe / pressure washable and robust
- Collect more data to train AI models to detect all common beef cuts
- Implement further label non-compliance issues and accept common export languages (Mandarin, Arabic etc)
- Use the camera rig and AI software to solve other detection challenges in a processing environment

Remote Inspection

This project part explored the use of remote inspection technologies such as smart glasses to facilitate remote auditing and reduce the cost of compliance. The research team engaged with over 20 organisations located in almost every Australian state. The participants were compromised of both meat processors, domestic and federal audit Agencies. This engagement involved shipping the smart glasses solution to them free of charge, user training, and audit support for all participating organisations.

During this work, the research team worked on developing new innovative software features for the remote inspection solution such as data capture and innovations in cyber security of that data. In some cases these new features were found to both improve the audit experience and for the more experimental work, demonstrated there are innovative methods that can be used to secure the authenticity and trust of audit data.

The research team observed over 26 real domestic and international export food safety audits could be facilitated remotely in either partial or whole. In the case where only a partial amount of the audit could be facilitated, other technologies such as computer based screenshare, document share and emails would cover the remaining parts.

Additional to the support of remote audits was the exploration of other use cases of the technology. The research team observed over 17 remote maintenance and 9 staff training sessions. It was also highlighted that the technology was utilised for domestic/international customer tours of the facility, and used for other inspection tasks like ante-mortem and animal health checks.

It is recommended that the following occur to continue building on the success from this project:

- Continue hardware and software support for existing and new meat processors
- Continued support and monitoring of other remote inspection use cases.
- Continued software development and testing of new features that improve the auditing experience and help save costs.
- Work with domestic, federal and international audit agencies to develop standards which accept remote inspection.
- Develop a remote audit certification for processors and auditors to confirm competency before conducting an audit

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9.0 Appendices

9.1 Appendix 1

BLV_Business_Case.pdf

9.2 Appendix 2

Smart_Glasses_Business_Case.pdf