Process Monitoring for the Australian Meat Industry – A Comparative Industry Trial

PROJECT CODE:	2018-1070
PREPARED BY:	Jessica Jolley, Andreas Kiermeier, John Sumner
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ACRONYMS

AMIC	Australian Meat Industry Council
AMPC	Australian Meat Processor Corporation
APC	Aerobic Plate Count
APL	Australian Pork Limited
AQIS	Australian Quarantine and Inspection Service
CMA	Carton Meat Assessment
DAWR	Department of Agriculture and Water Resources
EMIAC	Export Meat Industry Advisory Council
ESAM	*E. coli* and *Salmonella* Monitoring
EU	European Union
FSAHSC	EMIAC Food Safety and Animal Health Subcommittee
MHA	Meat Hygiene Assessment
MI&QA	Meat Inspection and Quality Assurance
MLA	Meat and Livestock Australia
NCMMP	National Carcase Microbiological Monitoring program
OPV	On-Plant Veterinarian
PHI	Product Hygiene Index
QA	Quality Assurance
SARDI	South Australian Research and Development Institute
STEC	Shiga-toxin producing *E. coli*
TVC	Total Viable Counts (see also APC)
ZT	Zero Tolerance

1.0 EXECUTIVE SUMMARY

Objectives and conduct of the project

AMPC Project 2018:1070 *"Process Monitoring for the Australian Meat Industry – A Comparative Industry Trial"* involved 12 export establishments (six bovine, three ovine and three porcine).

The objectives of the project were to:

1. Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to:
    a. Establish/revise limits for modified Meat Hygiene Assessment (MHA) for carcases, bulk meat, primals and offals; and
    b. Establish limits and frequency of testing for Aerobic Plate Counts (APC) and *E. coli* for carcases, bulk meat, primals and offals.
2. Assess the performance, ease of use and understanding of the revised system by DAWR on-plant veterinary staff and establishment quality assurance staff.
3. Design a timely reporting and responding system based on recording and reporting spreadsheets with clearly identified performance criteria.
4. Provide information and data to assist the DAWR to develop equivalence submissions for international markets.

Over the period (October 2017 – October 2018), a total of 27,157 microbiological results and 1,645,537 visual checks were collected.

These data were analysed and discussed on a monthly basis with a Reference Panel comprising representatives of the DAWR, industry, AMPC, MLA and APL.

The project team also prepared analyses for each participating establishment for discussion throughout the project.

At the conclusion of the information-gathering phase of the project, data were analysed to inform possible alternative monitoring regimes for microbiological and visual testing of carcases, bulk meat, primals and offals.

Project outcomes

The outcomes of the project are presented under each objective.

Objective 1a: Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to establish/revise limits for modified Meat Hygiene Assessment (MHA) for carcases, bulk meat, primals and offals.

Of the 1,645,537 data points gathered from participating establishments, 476,160 were from carcases, 176,399 from bulk meat, 104,161 from primals and 888,817 from offals.

Data analysis for each individual establishment is presented in Appendix 6 with key findings that:

1. While an extremely large number of visual checks were carried out by each establishment, there were considerable differences in the number of visual checks completed between establishments, influenced by the number of product lines or by management decisions to use more intensified checking.
2. Overall, visual hygiene performance was very good and limits were breached very infrequently (see also Appendix 6).

3. Carcase, bulk meat, primal and offal daily average scores were generally below the limits of 1.5, 0.5, 0.5 and 0.5 respectively.
4. The majority of defects were minor with very few zero tolerance defects.
5. An alternative system was evaluated based on a reduced frequency of testing whereby carcases, bulk meat, primals and offals were each monitored three times a day, with 10 samples assessed on each occasion.
6. Under the alternative system:
   - Three of the twelve participating establishments would have one alert every ten years from carcase MHA.
   - For bulk meat, the use of a daily average would have resulted in more frequent failures for some plants, the majority of which involved manufacturing defects.
   - Visual checks for primals, which are not a requirement under the current system, would result in occasional alerts under the alternative system.
   - However, despite numerous discussions with the DAWR, the project Reference Panel and industry, consensus could not be reached on which attributes were considered "food safety" or "non-food safety".
   - This was prominent among the factors that prevented the industry from suggesting and agreeing on an alternative system of visual monitoring.
7. Accordingly, the need is identified for a more comprehensive review of MHA and CMA, including which defects should be monitored as part of regulatory compliance; defect severity criteria (definitions of a Minor, Major and Critical) and practical elements of what action should be taken in the event of an Alert.

Objective 1b: Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to establish limits and frequency of testing for Aerobic Plate Counts (APC) and *E. coli* for carcases, bulk meat, primals and offals.

Of the 21,157 data points gathered from participating establishments, 11,512 were from carcases, 9,872 from bulk meat, 2,169 from primals and 3,604 from offals.

Data analysis for each individual establishment is presented in Appendix 4 with key findings that:

1. Carcase TVCs for beef ranged between 0-1 log cfu/cm^2 over the 13-month trial, while those for sheep and pigs were 0.5-1.0 log cfu/cm^2 higher.
2. In general, primal and bulk meat TVCs were approximately one log higher than those of carcases.
3. Offal TVCs were approximately 4 log cfu/g with high counts being found on head offals such as tongues and on intestinal offals such as mountain chains and green runners.
4. *E. coli* was detected on beef, sheep and pig carcases with prevalence ranging 0.5-3.5%, 20-32% and 3.5-5%, respectively.
5. For all three species, *E. coli* was isolated rarely from primals, and more frequently from bulk meat, where occasional high counts were recorded.

In terms of conformance with criteria set out in the *Microbiological Manual for sampling and Testing of Export Meat and Meat products* (DAWR, 2018; Appendix 1) for carcases, three beef establishments failed thirteen windows (11 for TVC and 2 for *E. coli*); one sheep establishment failed five windows (for *E. coli*) and one pig establishment failed one window (for TVC).

As required under Objective 1b, the following alternative monitoring systems were proposed and discussed with the project Reference Panel and with industry representatives.

Alternative 1: "Test what you sell", with product tested proportionally according to the volume of product sold was ultimately eliminated because it became clear that carcase testing would remain a requirement by major overseas markets.

Alternative 2: A system closely aligned with that of New Zealand specifications was also eliminated because, although Australia has a large ESAM database and baseline information, it was considered that Australia lacked specific testing regimes to support a NZ-like system.

Alternative 3: Reduction of the frequency of carcase testing, with re-allocation of testing to bulk meat, primals and offals was considered suitable and could be justified for further evaluation; this alternative became the Proposed System.

The consensus was that Alternative 3 was the preferred option, with bovine and porcine/ovine products to be tested at a frequency of 1 in 1000 and 1 in 3000 carcase equivalents, respectively. The proposed system was based on:

- A single set of criteria for all species as they are all considered as 'meat' by consumers.
- A moving window of n=15 as per the current system for carcases, bulk meat and primals; a moving window of n=5 for offals.
- Setting c=1 (carcases, bulk meat and primals) whereby establishments can have one result over the m-limit in a window of 15 samples (c=3 for offals).
- Carcase TVC m-limit of 10,000 cfu/cm^2 (the same as the strictest NZ M-limit for carcases and below the EU M-limit for carcases of 100,000).
- Bulk meat and primal TVC m-limit of 100,000 cfu/(cm^2 or g), based on commercial criteria (e.g. major supermarkets) and reflecting an accepted 1-2 log difference between carcase and bulk meat TVC results.
- All *E. coli* m-limits are 100 cfu, based on standard commercial limits and the US limit of 100 cfu for beef carcases.
- Offal criteria are as per the agreed China protocol.
- Removal of *Salmonella* testing due to a history of very low prevalence but with the suggestion that *Salmonella* testing could continue as part of future baseline surveys.

Performance criteria for all products are presented in Table ES1.

Table ES1: Performance criteria for proposed system

	TVC			***E. coli***		
	n	**c**	**m-limit**	**n**	**c**	**m-limit**
Carcase	15	1	10,000	15	1	100
Bulk meat	15	1	100,000	15	1	100
Primals	15	1	100,000	15	1	100
Offal	5	3	1,000,000			

A comparison of the current and proposed systems is presented in Table ES2 for each participating establishment from which it can be seen that the proposed system triggers alerts at nine establishments, with bulk meat, primals and offals contributing substantially to this total.

Table ES2: Comparison of the number of TVC and E. coli alerts under the current system (carcase only) and proposed system (carcase/bulk meat/primals/offal).

	Number of TVC Alerts		Number of *E. coli* Alerts	
Establishment	**Current system (carcase)**	**Proposed system (carcase/bulk meat/primals/offal)**	**Current system (carcase)**	**Proposed system (carcase/bulk meat/primals/offal)**
Beef				
A	11	4.0	0	0
B	0	0	0	0
C	0	0.1	0	0
D	0	0	1	0.8
E	0	0	1	0.1
F	0	0	0	0.2
Sheep				
G	0	0	0	1.0
H	0	0	0	0
I	0	0	5	5.0
Pig				
J	1	0	0	0
K	0	0	0	0
L	0	0	0	0.1

Objective 2: Assess the performance, ease of use and understanding of the revised system by DAWR on-plant veterinary staff and establishment quality assurance staff.

The trial protocols and revised visual and microbiological monitoring systems were explained and discussed on three occasions with each plant's quality assurance staff and management: at inception, at the midway point and at the end of the trial. On-plant veterinary staff attended some discussions.

On two of these three occasions the monitoring spreadsheet (see Objective 3) was demonstrated. Staff supported inclusion of end-product testing (bulk meat, primals and offal) as part of the regulatory monitoring program and the reporting tool was well received both for its ease of use and for its real-time impact.

Objective 3: Design a timely reporting and responding system based on recording and reporting spreadsheets with clearly identified performance criteria.

An Excel spreadsheet was developed for entering all data collected as part of this project. The spreadsheet contains separate data entry sheets for carcases, bulk meat, primals and offal, for both microbiological and visual results. In addition, a summary sheet was included to summarise all monitoring results for any given month and to display Alerts on a real-time basis, i.e. as soon as the data had been entered.

Objective 4: Provide information and data to assist the DAWR to develop equivalence submissions for international markets.

A series of position papers was prepared which may assist establishments and the DAWR to frame a proposal to overseas countries for a change in the way Australia monitors products in process and products as they enter the marketplace.

Material in these documents was drawn largely from work completed as part of three AMPC projects:

- "*Process Control Monitoring – Is there a better way?"* (AMPC Project 2017-1068)
- "*Process Monitoring for the Australian meat industry – a comparative industry trial*" (AMPC Project 2018-1070)
- "*Research and development in the Australian red meat industry: its impact on food safety and shelf-life*" (AMPC Project 2018-1086)

The individual position papers are:

1. The modern Australian slaughter and dressing system
2. Carcase hygiene – the National Carcase Microbiological Monitoring Program
3. Global comparisons – Australian meat in international trade
4. Risk of STEC illness in Australia from meat consumption.

These position papers are presented in Appendix 8.

Conclusions and recommendations

Regarding visual hygiene monitoring it is concluded that:

1. Establishments undertake a huge amount of visual testing of carcases and of final products, bulk meat and offals.
2. The number of checks varies widely between establishments and is not directly related to the volume of production.
3. Overall, visual hygiene performance was very good and limits were breached very infrequently.
4. Despite numerous meetings between industry and representatives and the project Reference Panel no consensus could be reached on what might comprise an alternative system for visual monitoring.

Accordingly it is recommended that a comprehensive review be undertaken of the current "Meat Hygiene Assessment" requirements, including which defects should be monitored as part of regulatory compliance; defect severity criteria (definitions of a Minor, Major and Critical) and practical elements of what action should be taken in the event of an Alert.

Considering microbiological testing data gathered by the twelve participating establishments, it is concluded that:

1. The microbiological profile of bovine, ovine and porcine carcases confirms the substantial improvements recorded over recent decades by the ESAM database and by national baseline surveys.
2. The microbiology of bulk meat, primals and offals conforms well with limits imposed by other countries (e.g. New Zealand) and by commerce (e.g. supermarkets).
3. A proposed system based on testing carcases, bulk meat, primals and offals would provide better information to establishments and their customers.

Accordingly it is recommended that the industry and the department pursue with overseas markets the possibility of amending the present agreed system based solely on carcase monitoring to include bulk meat, primals and offals.

2.0 INTRODUCTION

Background

Australia has been testing meat for export as part of the regulatory system for more than twenty years, particularly manufacturing meat destined for grinding in the USA.

In 1998, the Australian Quarantine and Inspection Service (AQIS, now Department of Agriculture and Water Resources, DAWR) implemented the *E. coli* and *Salmonella* Monitoring (ESAM) program. The program, now known as the National Carcase Microbiological Monitoring program (NCMMP), is performed by all export establishments. Establishments monitor their slaughter and dressing performance using three-class moving window sampling plans (DAWR, 2018); different values for the moving window-based microbiological criteria have been established for different species, including moving window (sample) size (n), acceptance number (c), marginal limit (m) and unacceptable limit (M) (Appendix 1). When the moving window criteria are breached, establishments are required to take action.

The criteria were based on an examination of ESAM data from January 2000 to June 2001 and calculated values with which a high proportion (approximately 95%) of carcases in each category would conform; the aspiration was that establishments regularly in the worst 5% would improve their processes (Vanderlinde *et al.* 2005); the authors counselled that it was important to reassess performance standards over time.

After two decades, the ESAM database now contains more than 1.2 million data points (TVC, *E. coli* and *Salmonella*) for bovine (611,600), ovine (550,000) and porcine (98,000) carcases.

One of the criticisms of the present sampling and testing regime is that, while it serves the important purpose of assuring market access, it does not adequately inform process hygiene, with no credible root-cause being identifiable when an alert is triggered. In addition, monitoring of carcases, while clearly important, focuses on product that is only part way through the process, ignoring boning and further handling performance. Nor do ESAM data appear to align with, or inform, detection of a Shiga-toxin producing *E. coli* (STEC).

Purpose

In 2017, the South Australian Research and Development Institute (SARDI) published "*Process Control Monitoring – Is there a better way?*" (AMPC Project 2017-1068) – a critical analysis of the ESAM, Product Hygiene Index (PHI) and Meat Hygiene Assessment (MHA) programs as currently operated by Australian meat export establishments.

The report made recommendations for alternative monitoring procedures which required trialling by the industry prior to implementation. SARDI applied for and was granted research funding to trial alternative procedures in "*Process Monitoring for the Australian meat industry – a comparative industry trial*" (AMPC Project 2018-1070).

Scope

The trial generated microbiological and visual data from twelve export establishments (six bovine, three ovine and three porcine) based in every State of Australia and representing small, medium and large and hot and cold boning establishments.

Project objectives and approach

The broad objectives of the project were to generate data to evaluate the proposed alternative monitoring system and enable further refinement. An iterative approach was followed in which the current and a series of alternative microbiological testing regimes were evaluated to determine each establishment's compliance, at the end of which one alternative system was developed.

Limitations to the research

Due to market access constraints, establishments were not permitted to evaluate an alternative system *per se.* To overcome this limitation, each establishment gathered a range of data (both microbiological and visual) in excess of that required under the ESAM and MHA programs, allowing the researchers to formulate alternative systems; an ex-gratia payment for additional microbiological testing was provided to each participating establishment.

3.0 PROJECT OBJECTIVES

1. Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to:
    a. Establish/revise limits for modified Meat Hygiene Assessment (MHA) for carcases, bulk meat, primals and offals; and
    b. Establish limits and frequency of testing for Aerobic Plate Counts (APC) and *E. coli* for carcases, bulk meat, primals and offals.
2. Assess the performance, ease of use and understanding of the revised system by DAWR on-plant veterinary staff and establishment quality assurance staff.
3. Design a timely reporting and responding system based on recording and reporting spreadsheets with clearly identified performance criteria.
4. Provide information and data to assist the DAWR to develop equivalence submissions for international markets.

4.0 METHODOLOGY

Participating establishments

Twelve establishments (six beef, three sheep and lamb, three pork) were recruited to participate in this industry trial.

- JBS, Dinmore (beef)
- Teys, Beenleigh (beef)
- Northern Co-operative Meat Company, Cassino (beef and pork)
- Greenham, Smithton (beef)
- Midfield Meats, Warrnambool (beef and sheep)
- M.C. Herd, Corio (beef and sheep)
- Fletcher International Exports, Albany (sheep)
- Big River Pork, Murray Bridge (pork)
- Seven Point Pork, Port Wakefield (pork)

The criteria for selection of establishments was based on:

- A range of large and small establishments, identified by daily throughput
- Geographical location, spread across Australia
- Hot and cold boning

- On-plant versus commercial laboratories
- Single-species versus multi-species establishments
- AMIC versus non-AMIC establishments

Collection of data

The trial commenced with a 'shake-down' month (October 2017) before running for twelve months from November 2017 to October 2018. Both microbiological and visual assessment data were collected as outlined below.

Microbiological

- Carcase TVC & *E. coli*
- Bulk meat TVC & *E. coli*
- Primal TVC & *E. coli*
- Offal TVC

Visual

- Carcase MHA
- Carton Meat Assessment (CMA)
- Primal MHA
- Offal MHA

The testing required by the current and trial regimes is summarised in Table 1. It should be noted that establishments currently test bulk carton meat for TVC and coliforms, although no action limits are established for these.

Table 1: Scope of data gathered in the trial.

	Requirements	
	Current (DAWR, 2018)	**Trial**
Microbiological		
Carcase TVC, *E. coli*	Yes	Yes
Bulk meat TVC	Yes	Yes
Bulk meat *E. coli*	No	Yes
Primal TVC, *E. coli*	No	Yes
Offal TVC	No	Yes
Visual		
Carcase MHA	Yes	Yes
CMA	Yes	Yes
Primal MHA	No	Yes
Offal MHA	Yes	Yes

A protocol for the trial was developed which gave details on additional sample collection for microbiological testing and visual assessment. The protocol was distributed to establishments and discussed with key staff in the lead up to the trial (Appendix 2).

Microbiological testing methods

Carcase and bulk meat samples were gathered and tested for indicator organisms at the frequency as set out in the DAWR's Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (DAWR, 2018; Appendix 1).

Primal and offal samples were tested at a carcase equivalent sampling frequency of 1 in 1000 for beef and 1 in 3000 for sheep and pork. Primal samples were gathered by sponge swabbing primal cuts prior to packaging (Appendix 2). Offal samples were tested by excision sampling prior to packing and chilling or freezing, except in the case of one establishment (Establishment J) which tested chilled offals (Appendix 2).

Visual assessment methods

Carcase, bulk meat and offal visual assessment were as per the MHA guidelines (AQIS, 2002). Primal visual assessment was made as per CMA defect categories and severity scores. For visual assessment, defect categories (bone fragments, bruises, etc.) were reported in addition to the severity (Minor, Major, Critical).

Reporting of data

An Excel spreadsheet was developed for data entry of all data collected as part of this project (Appendix 3). The spreadsheet contains separate data entry sheets for carcases, bulk meat, primals and offal, for both microbiological and visual results. In addition, a summary sheet was included to summarise all monitoring results for any given month and display "Alerts" on a real-time basis, i.e. as soon as the data had been entered. Some establishments used this spreadsheet to record their results before sending to SARDI on a regular basis, while others used their existing data capture systems (e.g. iLeader) to provide, as far as possible, automated data extraction for SARDI.

Reporting of data to SARDI included Excel spreadsheets, pdf files, iLeader reports or htm files and were sent on a daily, weekly or monthly basis.

Statistical analysis

All microbiological and visual data were entered by SARDI into the Excel spreadsheet reporting template (see Reporting of Data), one for each establishment/species, and all statistical analyses were performed using the software program R (version 3.1.3, 2015).

The current system was evaluated by applying the moving window criteria to a data set and all window failures, based on specified criteria of c and m-limit parameters, were recorded. When a window failure occurred, the moving window was re-set.

Implicit within the present project was to consider alternative testing regimes. For reasons of market access, however, it was impossible to trial any alternative system *per se.* To circumvent this constraint, participating establishments undertook additional microbiological testing and, from the extended data set, it was possible to simulate the effect of an alternative system by extracting data at random from the data set.

For example, the alternative system selected as the most suitable was based on reducing the sampling of carcases to one-third. Accordingly, a subset of the microbiological data was formed by randomly selecting one from every three consecutive results from the year-long trial (thus maintaining any temporal trends in the data). The moving window criteria were then applied to the sub-sampled data sets and all window failures, given specified criteria of c and m-limit parameters, were recorded. When a window failure occurred, the moving window was re-set. This process was repeated 100 times for each establishment.

To simulate an alternative system of visual checking (thirty visual checks per day) all checks with at least ten samples were selected for each establishment. From this subset of data, three lots per date were randomly selected to give a minimum total of thirty checks per day. If there were less than three lots per date, random selection with replacement was used. Similar to the way that MHA results are determined, the total daily score was calculated and divided by the number of checks to give the daily average score. This daily average score was subsequently compared to the limits. This process was repeated 100 times for each establishment.

Comparison of system performance

The performance of microbiological criteria, such as those used for process monitoring (DAWR, 2018; Appendix 1), can be visualised and compared with the help of an operating characteristic (OC) curve (e.g. FAO/WHO, 2016). This OC curve displays the probability of acceptance, P(accept), on the y-axis and the level of microbial contamination on the x-axis; the curve drops from 100% acceptance to 0% acceptance in a sigmoid curve-like manner. An example is shown in Figure 1, which shows the OC curve calculated for the *E. coli* on hot-boned cattle carcases (DAWR, 2018; Appendix 1) i.e. the three-class sampling plan with:

- Sample/moving window size n=15;
- Acceptance number c=7, the maximum number of microbial counts between m and M in n consecutive results;
- Marginal microbial limit m=-1.1, the $\log_{10}$ of 0.08, the limit of detection and thus equivalent to an *E. coli* detection, which is specified as m=0 in Table 4 of DAWR (2018) (Appendix 1); and
- Unacceptable limit M=1.7, the $\log_{10}$ of 50, the value of M specified in Table 4 of DAWR (2018) (Appendix 1).

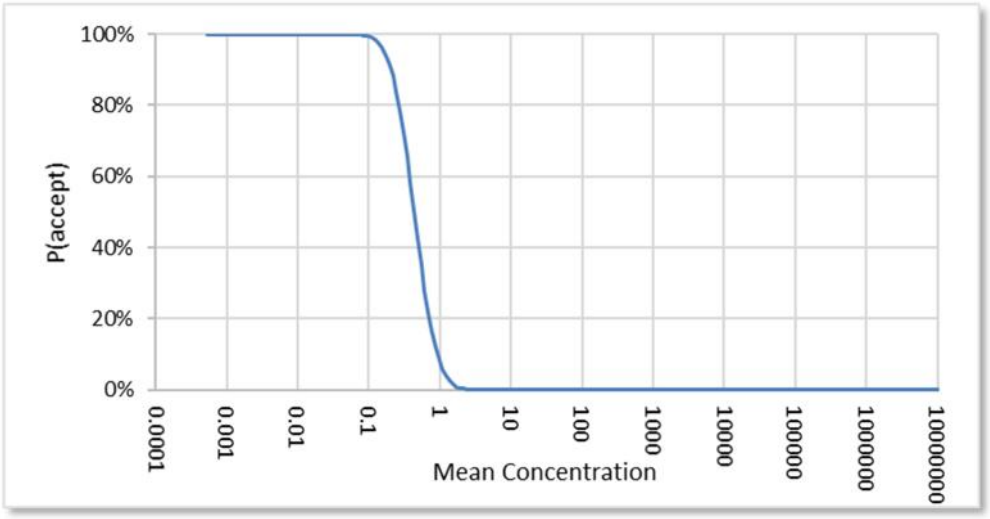

Figure 1: OC Curve for the sampling plan for hot-boned carcase (DAWR, 2018; Appendix 1).

In addition to the values stated above, the assumptions were made:

1. Microbial $\log_{10}$ concentrations are approximately normally distributed, and
2. The standard deviation (SD) of the $\log_{10}$ concentrations between samples is equal to 0.65 $\log_{10}$ cfu/cm^2 (estimated from the trial data).

The first assumption affects how the probability of acceptance is calculated, in particular, how the mean concentration and the probability of acceptance are related. Hence, if this assumption is not met it will affect at what point the OC curve drops i.e. could result in a shift in the OC curve to the left or right. The second assumption affects the steepness of the curve, with smaller values of SD resulting in steeper curves.

When comparing OC curves of two or more sampling plans neither of these two assumptions are of particular importance, provided the same assumption is made for all plans being compared i.e. the shape of the curve will be very similar, though may be shifted left/right.

In the case of the current project, we are interested in comparing not just two sampling plans, but two systems of process monitoring, consisting of:

A. The current system, which results in Alerts (i.e. acceptance/rejection of process hygiene) from carcase sampling only, and
B. The proposed system, which results in Alerts from carcase, bulk meat and primal sampling and testing.[1]

To compare these two systems, the probability of acceptance needs to be calculated for different levels of microbial (carcase) contamination. This process is straightforward as demonstrated above for hot-boned carcases (Figure 1). However, this process is more complicated for the proposed system, as acceptance only occurs when all three components – carcases, bulk meat and primals – are acceptable.

The calculations were performed as follows:

- For a given proposed sampling plan (n, c, m-limit), the probability of acceptance was calculated for carcases, bulk meat and primals, denoted as $P(A_c)$, $P(A_b)$ and $P(A_p)$. Data from establishments (Appendix 4) indicated that the microbial concentration of bulk meat and primals were higher than carcases, which may be due to:
    a) carcase samples originating from three specific sites only, while bulk meat and primals receive more handling, are in contact with more surfaces, and may originate from any part of the carcase; and
    b) bulk meat samples being collected using excision/small meat samples, rather than swab samples which were used for carcases and primals.

  Hence, a suitable offset in microbial concentration between carcase and bulk meat and between carcase and primal results was estimated. These offsets were used to adjust the mean concentration (which determines the probability of acceptance) for bulk meat and primals, while allowing a single x-axis to be used.
- The three probabilities of acceptance were multiplied to calculate the probability of acceptance under the system (i.e. all three components resulting in acceptance). This step assumes that the three probabilities are independent from each other i.e. a rejection in one component does not affect the probability of rejection in another component.
- This assumption seems reasonable on the basis of previous work by Rogers (2015), who concluded an investigation of carcase versus carton results with: *"Carton results tend to have little relation to carcase results. Boning rooms appear to have the effect of evenly distributing the contamination and resulting in reasonably consistent carton results regardless of the carcase results on a given day or week."* In addition, carcase and bulk/primal results are not matched (neither by carcase, nor by carcase site) and hence any relationship would be expected to be very weak, if present. A violation of this assumption would have the effect of shifting the OC curve to the right, though this shift is likely to be small.

Conduct of the project

Through the duration of the project (October 2017 – January 2019), the SARDI team continually liaised with a Reference Panel, industry experts, the DAWR and with each establishment.

[1] For the purpose of this comparison, offal sampling and testing is not included.

Reference Panel

A Reference Panel was established to:

- Have oversight of the project and to disseminate information to their stakeholders in almost real time during the project.
- Comprise one member nominated from each of AMIC, non-AMIC companies, one pork processor, APL, MLA, AMPC and two members from DAWR, together with the SARDI team.

The members of the Reference Panel were:

- David Lean/Matthew O'Bryan (AMPC)
- Heather Channon (APL)
- Ian Jenson (MLA)
- Mark Salter (DAWR)
- Jason Ollington (DAWR)
- Mary Wu/Stacey McKenna/Willie Rijnbeek (AMIC)
- Michael Johnston (JBS Australia)
- Michael Bayer (Big River Pork)
- Andreas Kiermeier (Statistical Process Improvement Consulting and Training Pty Ltd)
- John Sumner (M&S Food Consultants Pty Ltd)
- Jessica Jolley (SARDI)

The Reference Panel met on a regular basis either via teleconference or face-to-face.

- 4th October 2017 (face-to-face, Sydney)
- 29th November 2017 (face-to-face, Sydney)
- 31st January 2018 (teleconference)
- 9th March 2018 (face-to-face, Sydney)
- 16th April 2018 (teleconference)
- 21st May 2018 (teleconference)
- 2nd August 2018 (teleconference)
- 18th September 2018 (face-to-face, Sydney)
- 3rd December 2018 (face-to-face, Melbourne)

At each Reference Panel meeting, an update on the progress of the trial and the trial results were presented and discussed.

Industry expert panel

The SARDI team consulted a panel of industry experts on a range of logistical aspects pertaining to microbiological and visual testing via several teleconferences and two face-to-face meetings (16 July and 30 October 2018).

Establishment on-site discussion

The SARDI team visited each establishment participating in the industry trial on three occasions through the trial:

1. At the commencement (September 2017), to inform key establishment staff about the project background, objectives, plan and the sampling, testing and reporting requirements for both microbiological and visual aspects for the industry trial. The trial protocols and logistical arrangement were discussed during the meeting to ensure appropriate data collection and reporting.
2. Around the mid-way point (April-May 2018), providing updates on the microbiological and visual testing status of each individual establishment and the cohort in general.

3. At the end point of the trial (November 2018), when each establishment received a detailed presentation of their results. An appraisal was also made of how each establishment would fare based on a number of alternative testing regimes, and their feedback on each alternative was sought.

MINTRAC Meat Industry and Quality Assurance (MI&QA) Managers Network meetings

The objectives of the project, plus an update of its progress were presented at AMPC/MINTRAC MI&QA meetings in Melbourne, Brisbane, Adelaide, Perth, Wagga Wagga, Sydney and Rockhampton during 2018.

MINTRAC MI&QA conference

The SARDI team gave two presentations at the AMPC/MINTRAC MI&QA Conference at Surfers' Paradise in October 2018:

- Process monitoring for the Australian meat industry – a comparative industry trial
- Australia's export meat products – how do they rate at the hygiene Olympics?

Export Meat Industry Advisory Council (EMIAC) Food Safety and Animal Health Subcommittee

A summary of data generated during the trial, together with the effect of alternative testing regimes on participating establishments were presented by the SARDI team to the EMIAC Food Safety and Animal Health Subcommittee in Brisbane on the 31st of October 2018.

Workshop with industry and DAWR

A workshop in Melbourne involving personnel from industry and the DAWR on 4th December 2018 considered the current and alternative microbiological testing regimes and developed a system suitable to all parties.

Briefing of DAWR and industry personnel

The research team presented summary findings from the project, including the proposed microbiological system and recommendations for visual monitoring, to industry and DAWR on 16 January 2019 in Canberra.

Position papers

To assist in the discussions with DAWR, four position papers with specific topics were developed, which contain information gathered by the SARDI team in three AMPC projects (AMPC 2017-1068, AMPC 2018-1086 and AMPC 2018-1070). These position papers may assist with prosecuting a case for change in negotiations with overseas jurisdictions and are included in Appendix 8**.**

5.0 PROJECT RESULTS

Project outcomes in outline

In outline, the project:

- Gathered data from twelve participating establishments in a timely and satisfactory manner.
- Collated a total of 27,157 microbiological results and 1,645,537 visual checks for analysis.
- Established that the twelve establishments selected were representative of the industry in terms of their process monitoring performance.
- Considered several alternative systems for microbiological and visual testing and submitted them for wide discussion within the industry and DAWR.

- Established a preferred alternative for microbiological monitoring acceptable to both industry and DAWR.
- Identified the need for a broader review of all aspects of visual assessment, including defect categories and criteria.
- Analysed the effect the proposed system would have on alerts, as evidenced by window failures.
- Supplied DAWR with background information which may be useful in negotiations with overseas jurisdictions.

Establishment selection

In Figure 2, Figure 3 and Figure 4, comparisons are made between mean TVC of carcases (cfu/cm^2) and bulk meat (cfu/g) as well as *E. coli* prevalence (%) of trial and non-trial establishments. From these it can be seen that, except for sheep carcase prevalence for *E. coli* where trial plants were on the higher prevalence end, the trial establishments were comparable with/representative of the rest of the industry. Additional comparisons are provided in Appendix 5.

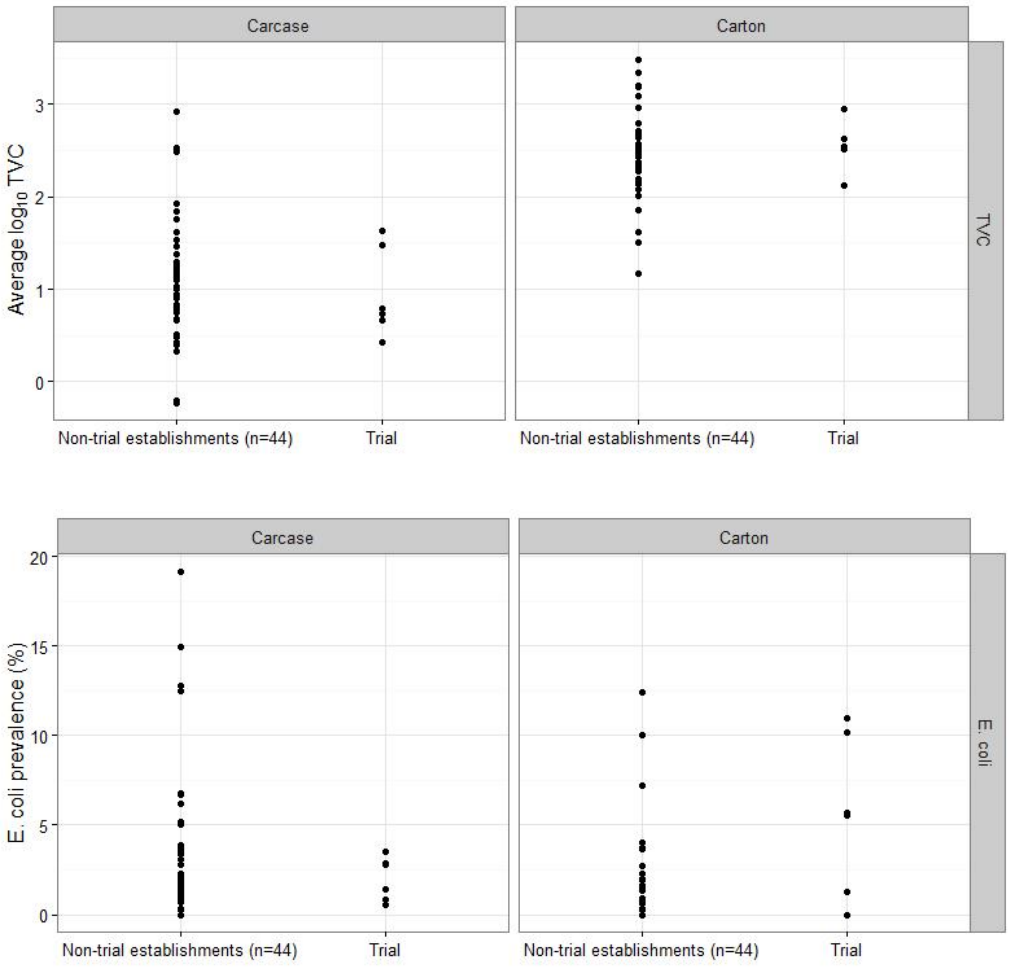

Figure 2: Mean TVC of beef carcases (cfu/cm^2) and bulk meat (cfu/g), together with prevalence of E. coli from trial and non-trial establishments; based on ESAM data from August 2017 to August 2018.

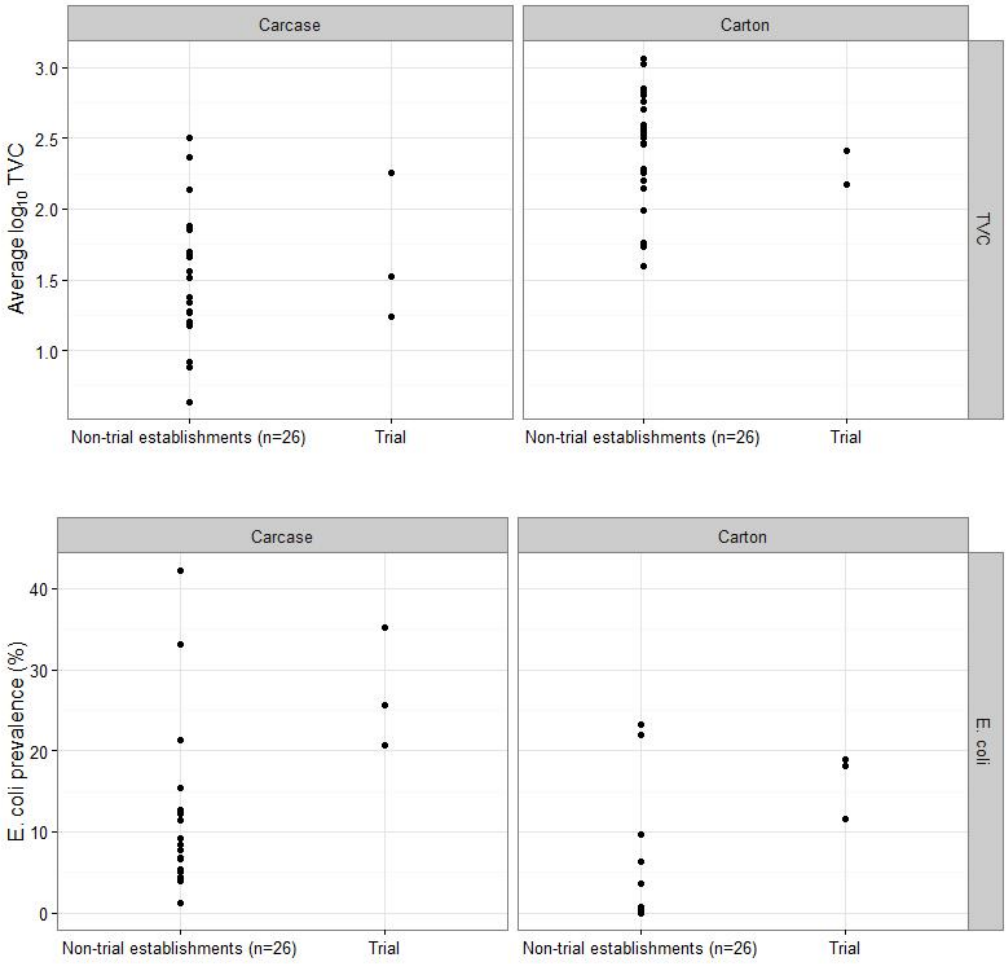

Figure 3: Mean TVC of sheep carcases (cfu/cm^2) and bulk meat (cfu/g), together with prevalence of E. coli from trial and non-trial establishments; based on ESAM data from August 2017 to August 2018.

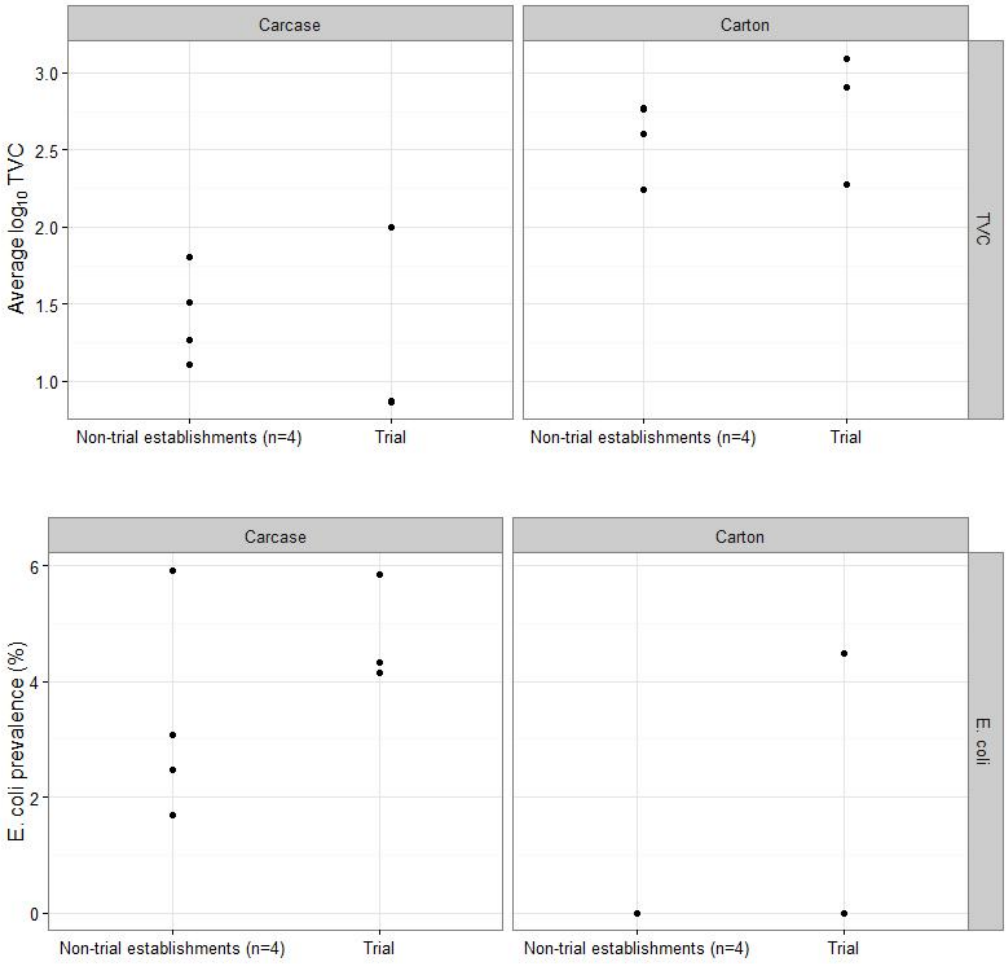

Figure 4: Mean TVC of pig carcases (cfu/cm^2) and bulk meat (cfu/g), together with prevalence of E. coli from trial and non-trial establishments; based on ESAM data from August 2017 to August 2018.

Objective 1b: Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to establish limits and frequency of testing for Aerobic Plate Counts (APC) and *E. coli* for carcases, bulk meat, primals and offals.

Establishments' trial data

During the trial period, 21,157 microbiological results were entered into the SARDI database (Table 2).

Table 2: Microbiological data submitted by Plants A-L from October 2017 – October 2018.

Establishment	Carcases	Bulk meat	Primals	Offals	Total
Beef					
A	414	424	118	129	**1,085**
B	561	0	0	134	**695**
C	2,130	2,090	389	601	**5,210**
D	1,341	1,318	284	414	**3,357**
E	836	1,007	254	265	**2,362**
F	775	1,164	230	277	**2,446**
Sheep					
G	1,209	1,198	281	636	**3,324**
H	878	0	0	68	**946**
I	1,606	1,693	274	562	**4,135**
Pigs					
J	756	362	156	238	**1,512**
K	656	433	88	182	**1,359**
L	350	183	95	98	**726**
Total	11,512	9,872	2,169	3,604	**21,157**

Each establishment's microbiological data were analysed by constructing temporal charts for TVC and *E. coli* for carcases and end products produced at that establishment; a typical output is presented in Figure 5 and Figure 6 for Establishment D. Similar plots are provided in Appendix 4 for all other establishments/species.

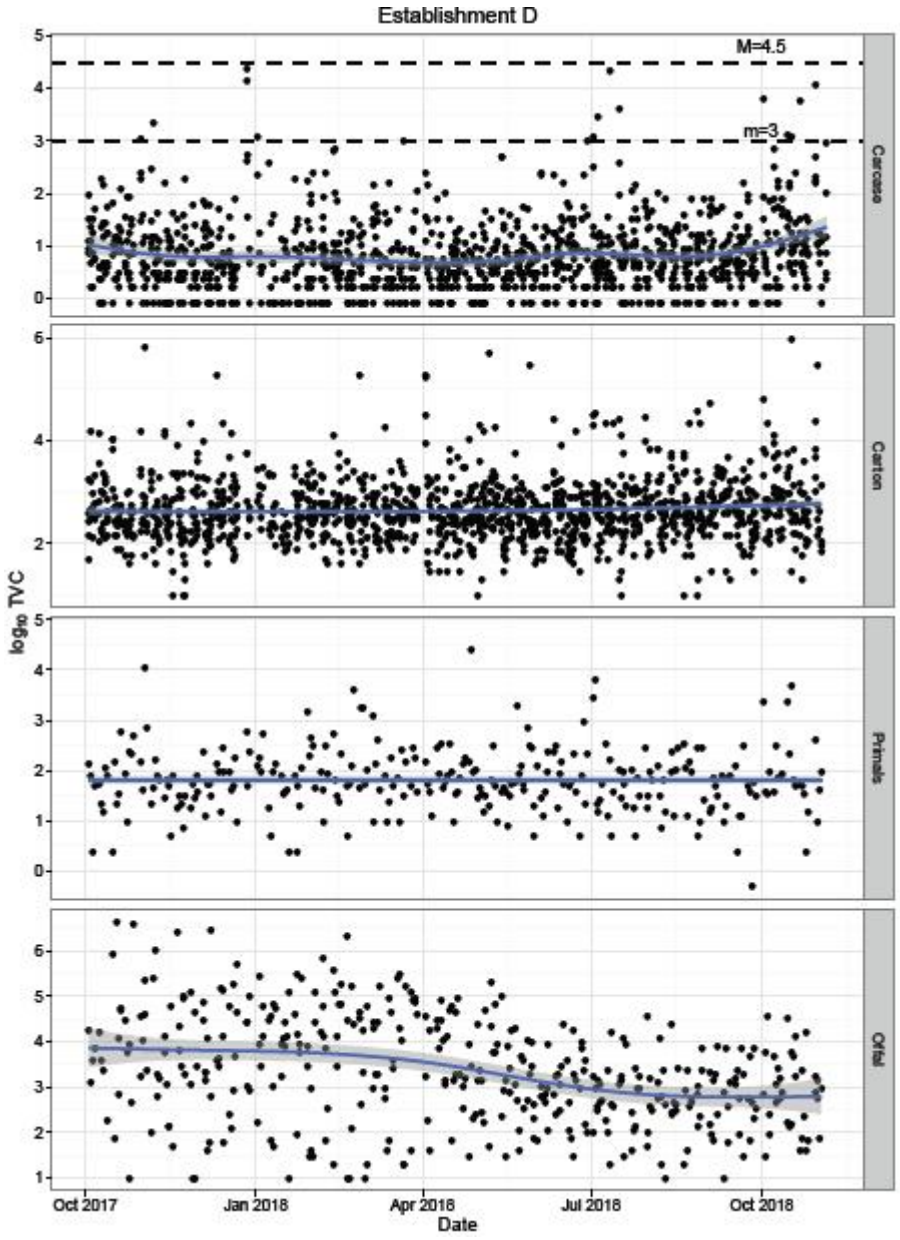

Figure 5: Summary data for TVC of carcases and primals (cfu/cm²) and bulk meat and offal (cfu/g) produced at Establishment D during October 2017 to October 2018.

As can be seen from Figure 5, carcase TVCs ranged between 0-1 log cfu/cm^2 over the 13-month trial, with few counts exceeding current m and M values. Primal and bulk meat TVCs were approximately one log higher than carcase TVCs. Offal TVCs were approximately 4 log cfu/g with high counts being found on head offals such as tongue and intestinal offals such as mountain chains and green runners. No windows were broken for carcases.

For carcase and end products, there was little evidence of seasonal effects on TVCs. At Establishment D, offal counts improved likely due to improved cleaning of offal chutes, an action which followed the gaining of information on bacterial loadings of offals during the early stages of the trial.

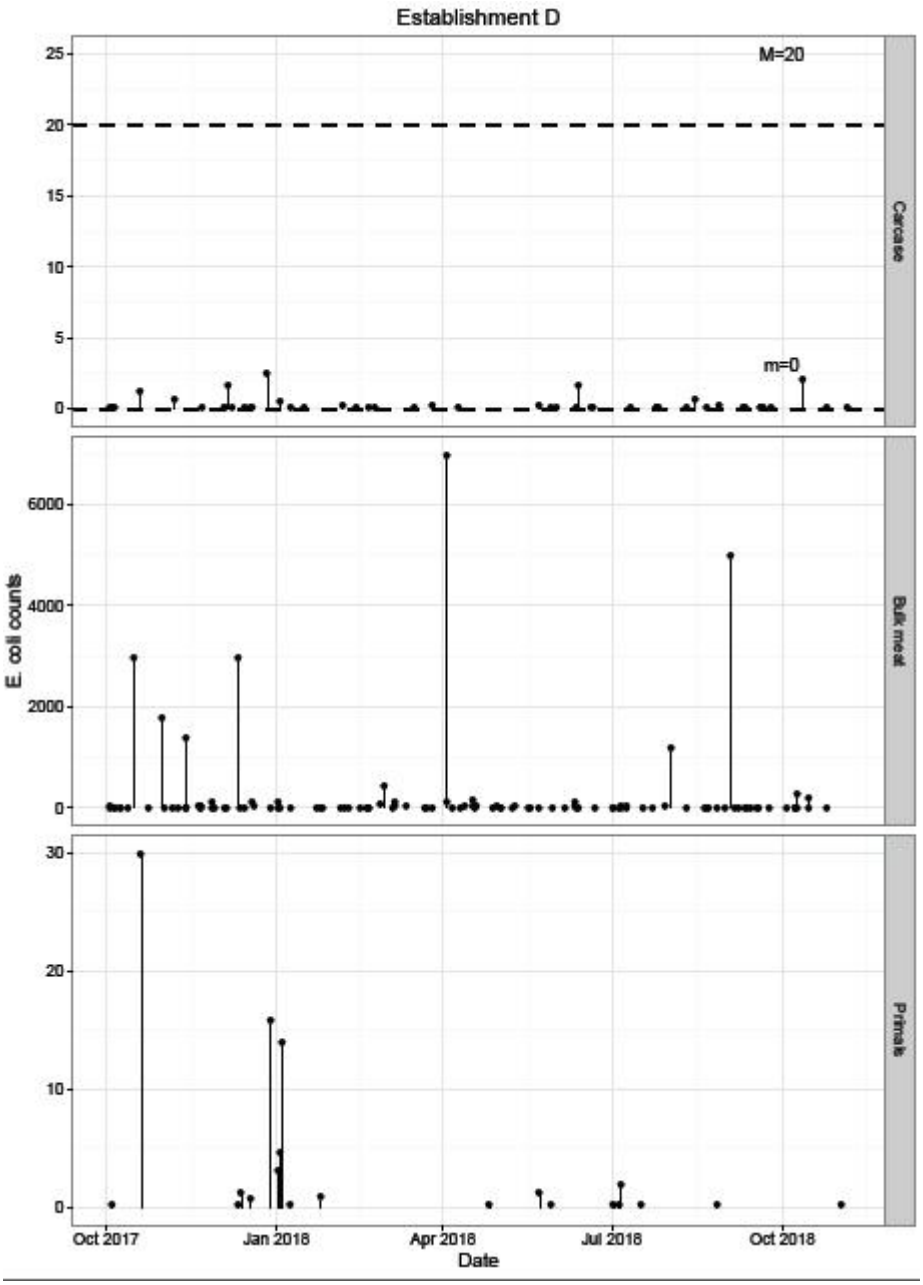

Figure 6: E. coli counts on carcases, bulk meat and primals produced at Establishment D during October 2017 to October 2018.

From Figure 6, it can be seen that *E. coli* was isolated rarely from carcases and primals, but more frequently from bulk meat, where occasional high counts were recorded; no windows for m or M on carcases were broken.

A profile of TVC counts and *E. coli* prevalence on primals tested at Establishment D is presented in Figure 7 and Table 3; TVC counts on offals are shown in Figure 8 and indicate that, at Establishment D, median counts were between 2 and 4 log cfu/g.

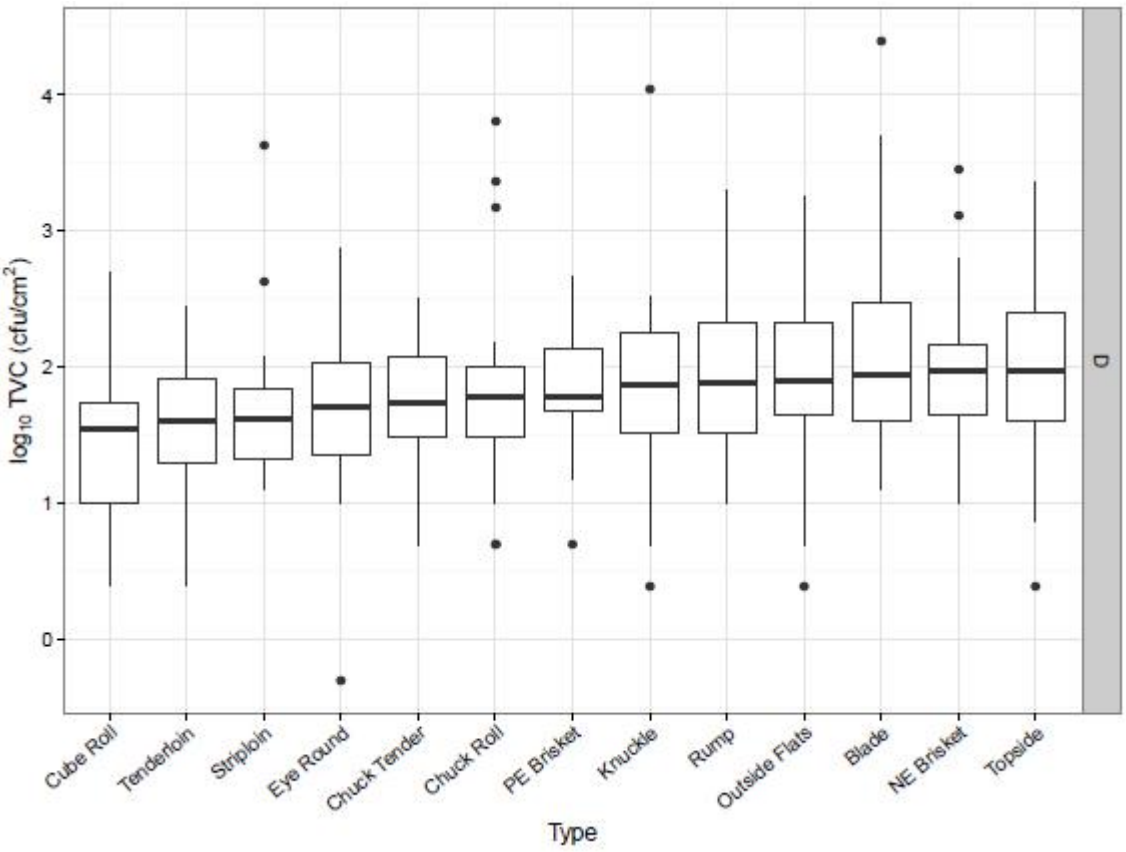

Figure 7: TVC and E. coli prevalence on primals tested at Establishment D.

Table 3: E. coli prevalence (%) for primal products tested at Establishment D.

Primal Type	# of Samples	# of *E. coli* Detections	*E. coli* Prevalence (%)
Eye Round	21	3	14.3
Blade	21	3	14.3
NE Brisket	22	3	13.6
Topside	22	2	9.1
Outside Flats	22	2	9.1
Chuck Roll	22	2	9.1
Tenderloin	22	1	4.5
Striploin	22	1	4.5
PE Brisket	22	1	4.5
Knuckle	22	1	4.5
Chuck Tender	22	1	4.5
Rump	22	0	0.0
Cube Roll	22	0	0.0

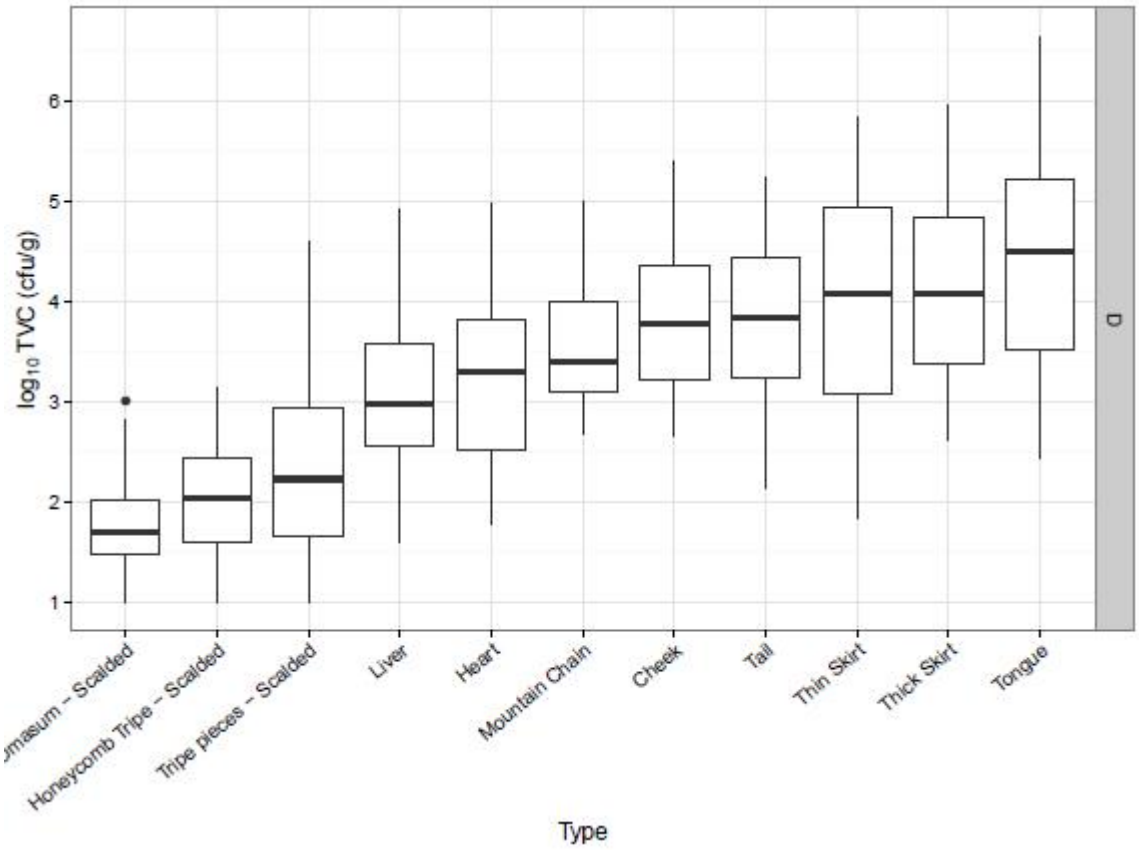

Figure 8: TVC on offals tested at Establishment D.

Conformance with current DAWR criteria

In the Microbiological Manual for Sampling and Testing of Export Meat and Meat Products, the DAWR (2018) outline the requirements and criteria of ESAM in order to verify carcase slaughtering and chilling operations. The DAWR has established limits for TVC and generic *E. coli* that are assessed on a moving window of n=15 consecutive samples to allow for continuous evaluation of performance. A window failure occurs if the number of marginal results (> m but ≤ M) exceeds c, or a single result exceeds the unacceptable level (M); such window failures will trigger an Alert (Appendix 1).

Testing criteria for TVC and *E. coli* for each species (beef, sheep and pork) are considered separately below; *Salmonella* detections were not included in the present project.

Beef

Criteria for beef are:

- 1 in 300 carcases (TVC, *E. coli*).
- 1 in 300 carcase equivalent bulk meat tests (TVC, coliforms).
- No testing requirements for primals or offal.

Carcase	n	c	m	M
TVC**	15	3	1,000	31,625
E. coli	15	3 (7*)	0	20 (50*)

*Hot boned carcases

**Requirement for EU access only

Based on these criteria, failed windows for beef carcases during the period October 2017 to October 2018 were confined to three plants (Table 4).

Table 4: Failed windows for TVC and E. coli on beef carcases from participating trial establishments; in the "m" column are listed the number of failures due to exceeding "m" too many times in the moving window, while in the "M" column are listed the number of failures due to exceeding "M".

Establishment	TVC failed windows		*E. coli* failed windows	
	m	M	m	M
A	6	5	0	0
B	0	0	0	0
C	0	0	0	0
D	0	0	1	0
E	0	0	1	0
F	0	0	0	0

Sheep

Criteria for sheep and lamb are:

- 1 in 1000 carcases (TVC, *E. coli*).
- 1 in 1000 carcase equivalent bulk meat tests (TVC, coliforms).
- No testing requirements for primals or offal.

Carcase	n	c	m	M
TVC*	15	5	1,000	31,625
E. coli	15	7	5	100

*Requirement for EU access only

Based on these criteria, one establishment failed five windows over the period October 2017-October 2018 (Table 5).

Table 5: Failed windows for TVC and E. coli on sheep carcases; in the "m" column are listed the number of failures due to exceeding "m" too many times in the moving window, while in the "M" column are listed the number of failures due to exceeding "M".

Establishment	TVC failed windows		*E. coli* failed windows	
	m	M	m	M
G	0	0	0	5
H	0	0	0	0
I	0	0	0	0

Pigs

Criteria for pigs are:

- 1 in 1000 carcases (TVC, *E. coli*).
- 1 in 1000 carcase equivalent bulk meat tests (TVC, coliforms).
- No testing requirements for primals or offal.

Carcase	n	c	m	M
TVC*	15	5	3,162	31,625
E. coli	15	5	1	100

*Requirement for EU access only

Based on these criteria, one trial plant failed a window for pig carcases during the period October 2018 to October 2018 (Table 6).

Table 6: Failed windows for TVC and E. coli on pig carcases; in the "m" column are listed the number of failures due to exceeding "m" too many times in the moving window, while in the "M" column are listed the number of failures due to exceeding "M".

Establishment	TVC failed windows		*E. coli* failed windows	
	m	M	m	M
J	0	1	0	0
K	0	0	0	0
L	0	0	0	0

Alternative monitoring systems

Under the current ESAM system, establishments have collected data on carcase testing for over twenty years, a time when a significant proportion of meat was sold in carcase form. However, a much larger proportion of product is now sold in the form of trim/carton/bulk meat, primals and offal. Testing carcase, bulk meat, primals and offal provides a more holistic picture of product hygiene along the processing chain.

In the present project, the suitability of a number of alternative testing regimes was assessed, the underpinning criteria including:

- The desirability of reallocating resources between carcases and end products.

A history of improvement in carcase hygiene, particularly in recent years based on CSIRO research research and on national baseline survey data (Table 7, Table 8 and

- Table 9).
- Over the period 2007-2018, consistently low total bacterial loadings and prevalence of *E. coli* on beef, sheep and pig carcases.

Table 7: Beef carcase contamination in Australia 1964 to 2018.

	Number of samples	Mean log_{10} TVC (cfu/cm^2)	*E. coli* prevalence (% > 10 cfu/cm^2)	Reference
1964	70	3.9	22.5	Grau (1979)
1978	86	2.7	15.6	Grau (1979)
1994	1,063	3.2	9.2	Vanderlinde *et al.* (1999a)
1998	1,268	2.4	2.4	Philips *et al.* (2001a)
2004	1,147	1.3	0.2	Phillips *et al.* (2006a)
2018	5,939	0.8	0.02	Jolley *et al*. (2018)

Table 8: Sheep carcase contamination in Australia 1978 to 2018 (1978 data were gathered from a single abattoir, whereas baseline and survey data are national).

	Number of samples	Mean log_{10} TVC (cfu/cm^2)	*E. coli* prevalence (% > 10 cfu/cm^2)	Reference
1978	-	3.2	63.6	Grau (1979)
1994	470	3.9	55.5	Vanderlinde *et al.* (1999b)
1998	917	3.5	4.2	Philips *et al.* (2001b)
2004	1,117	2.3	4.8	Phillips *et al.* (2006b)
2018	3,581	1.6	1.4	Jolley *et al*. (2018)

Table 9: Pig carcase contamination in Australia 1997 to 2018.

	Number of samples	Mean log_{10} TVC (cfu/cm^2)	*E. coli* prevalence (%)	Reference
1997	360	3.8	29.3[1]	Coates *et al.* (1997)
2015	409	2.5	20.3[2]	Hamilton *et al.* (2015)
2018	1,762	1.4	5.4[2]	Jolley *et al.* (2018)

[1] based on a limit of detection 1 cfu/ 60 cm^2

[2] based on a limit of detection 1 cfu/ 300 cm^2

Three alternative systems were considered and the conformance of each establishment participating in the trial was analysed and compared with the current testing system:

- Alternative 1: "Test what you sell", with product tested proportionally according the volume of product sold.
- Alternative 2: Adopt a system closely aligned with that of New Zealand (Specifications for National Microbiological Database Programme, Ministry for Primary Industries, NZ Government, September 2016)
- Alternative 3: Reduce the frequency of carcase testing, with re-allocation of testing to bulk meat, primals and offals.

The merits and suitability of the current and each alternative system were discussed on several occasions with each participating establishment, with an industry expert panel, with the Reference Panel and at a workshop with DAWR and industry representatives.

This consultation process resulted in the elimination of Alternatives 1 and 2 because:

- In the case of Alternative 1, it was made clear that carcase testing would remain a requirement by major overseas markets.
- In the case of Alternative 2, enquiries established that New Zealand had, over the long-term, supplied relevant information to major markets to enable acceptance of a unique testing regime. While Australia has a large ESAM database and baseline information, it was considered that, at the present time, Australia would not have the specific data to support negotiations towards the NZ system.

However, discussions with all groups identified above did confirm that Alternative 3 would be an acceptable system for the industry and criteria within it could be proposed to major overseas markets.

Elements of Alternative 3 are presented in Table 10 and are justified as follows:

- Inclusion of bulk meat, primal and offal testing, not just carcase testing.
  Rationale: ESAM has collected data on carcase testing for over twenty years and indicates a good-performing, improving industry. A large proportion of end product sold to customers is in the form of primals, offal and trim/carton/bulk meat, rather than carcases. Testing carcase, bulk meat, primals and offal provides a more holistic picture of product hygiene along the processing chain and supports a reallocation of resources from carcases to end product.
- Sampling frequency is changed to 1 in 1000 carcases (bovine) and 1 in 3000 carcases (ovine and porcine). These values also indicate the frequency with which end products are tested, relative to the number of carcases produced.
  Rationale: As per first dot point, it is a reallocation of sampling and testing to include more end product and provide data that has previously not been collected or monitored as part of the regulatory system.

- Testing for TVC and *E. coli*; no *Salmonella* testing
  Rationale: Removal of *Salmonella* due to history of very low prevalence. It is suggested that *Salmonella* testing could continue as part of future baseline surveys.
- Setting new performance criteria for carcases, bulk meat, primal and offal based on:
  - A single set of criteria for all species as they are all considered as 'meat' by consumers.
  - A moving window of n=15 as per the current system for carcases, bulk meat and primals; a moving window of n=5 for offals.
  - Setting c=1 (carcases, bulk meat and primals) whereby establishments can have one result over the m-limit in a window of 15 samples, but two high counts will instigate a conversation between QA and the On-Plant Veterinarian (c=3 for offals).
  - Carcase TVC m-limit of 10,000 cfu/cm^2 (the same as the strictest NZ M-limit for carcases and below the EU M-limit for carcases of 100,000).
  - Bulk meat and primal TVC m-limit of 100,000 cfu/(cm^2 or g), based on commercial criteria (e.g. major supermarkets) and reflecting an accepted 1-2 log difference between carcase and bulk meat TVC results.
  - All *E. coli* m-limits are 100 cfu, based on standard commercial limits and the US limit of 100 cfu for beef carcases.
  - Offal criteria are as per the agreed China protocol.
- In the event of a broken window, an Alert will be triggered. The establishment must review the process to identify any factors that may have caused the Alert, take any corrective and preventative action to control those factors identified and discuss with the On-Plant Veterinarian.

Table 10: Performance criteria for proposed system

	TVC			*E. coli*		
	n	**c**	**m-limit**	**n**	**c**	**m-limit**
Carcase	15	1	10,000	15	1	100
Bulk meat	15	1	100,000	15	1	100
Primals	15	1	100,000	15	1	100
Offal	5	3	1,000,000			

Conformance with the proposed system

Beef

Based on the criteria for the proposed system as set out in Table 10, the number of Alerts for beef carcases and end product from the participating trial establishments are presented in

Table 11. The values in these tables were obtained using simulations as described in the Methodology and hence represent the average number of failures. For example, Establishment C has a value of 0.1 for bulk meat TVC which corresponds to, on average, one Alert for bulk meat TVC in ten years.

Table 11: Simulated average number of failed windows for TVC and E. coli on beef carcases and end product from participating trial establishments of the 13 month trial.

	Average # of Alerts per year						
	Carcases		Bulk meat		Primals		Offals
Establishment	TVC	*E. coli*	TVC	*E. coli*	TVC	*E. coli*	TVC
A	1.7	0	2.3	0	0	0	0
B	0	0	NA	NA	NA	NA	0
C	0	0	0.1	0	0	0	0
D	0	0	0	0.8	0	0	0
E	0	0	0	0.1	0	0	0
F	0	0	0	0.2	0	0	0

* NA denotes that an establishment does not produce a particular product during that shift.

Sheep

Based on the criteria for the proposed system Alerts for sheep carcases and end product from the participating trial establishments presented in Table 12 indicate that there would have been alerts for two of the trial plants based on *E. coli* exceeding 100 cfu/g in bulk meat.

Table 12: Simulated average number of failed windows for TVC and E. coli on sheep carcases and end product from participating trial establishments of the 13 month trial.

	Carcases		Bulk meat		Primals		Offals
Establishment	TVC Alerts	*E. coli* Alerts	TVC Alerts	*E. coli* Alerts	TVC Alerts	*E. coli* Alerts	TVC Alerts
G	0	0	0	1.0	0	0	0
H	0	0	NA	NA	NA	NA	0
I	0	0	0	5.0	0	0	0

* NA denotes that an establishment does not product a particular product during that shift.

Pigs

Based on the criteria for the proposed system, Alerts for pig carcases and end product from the participating trial establishments (Table 13) would occur rarely and only for one establishment.

Table 13: Simulated average number of failed windows for TVC and E. coli on pig carcases and end product from participating trial establishments of the 13 month trial.

	Carcases		Bulk meat		Primals		Offals
Establishment	TVC Alerts	*E. coli* Alerts	TVC Alerts	*E. coli* Alerts	TVC Alerts	*E. coli* Alerts	TVC Alerts
J	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0
L	0	0	0	0.1	0	0	0

Comparison between current and proposed systems

In Table 14 are shown the number of alerts for TVC and *E. coli* that occurred under the current system (based on carcases only) and under the proposed system (based on carcase, bulk meat, primal and offal). These results indicate that while there are fewer alerts for TVC for the trial plants under the new system, there are similar numbers of alerts for *E. coli*, emanating particularly from bulk meat, where some *E. coli* detections were high (Appendix 4). It should be noted that bulk meat samples can originate from anywhere on the carcase surface, while carcase samples represent only three specific sites.

Table 14: Comparison of the number of TVC and E. coli alerts under the current system (carcase only) and proposed system (carcase/bulk meat/primals/offal).

	Number of TVC Alerts		Number of *E. coli* Alerts	
Establishment	**Current system (carcase)**	**Proposed system (carcase/bulk meat/primals/offal)**	**Current system (carcase)**	**Proposed system (carcase/bulk meat/primals/offal)**
A	11	4.0	0	0
B	0	0	0	0
C	0	0.1	0	0
D	0	0	1	0.8
E	0	0	1	0.1
F	0	0	0	0.2
G	0	0	0	1.0
H	0	0	0	0
I	0	0	5	5.0
J	1	0	0	0
K	0	0	0	0
L	0	0	0	0.1

In addition to the above trial results, the sampling plans for carcases used by industry to assess process conformance (DAWR, 2018; Appendix 1) can be compared with the proposed system's performance. For this, the average difference in $\log_{10}$ TVC between carcase and bulk meat and between carcase and primals was calculated as 1.6 and 0.6, respectively. These values were used as the offsets to carcase microbial concentration, as described in "Comparison of system performance" (see Methodology). The same offsets were used for *E. coli* on the basis that the distribution of *E. coli* concentration is shifted to a lower mean, and thus results in more non-detects given the Limit of Detection of the test.

TVC

Below are shown the OC curves comparing the current and alternate systems for cold-boned bovine (Figure 9), ovine (Figure 10) and porcine carcases (Figure 11); the criteria for cold-boned bovine carcases were used as those for hot-boned carcases are less stringent (i.e. curve is to the right). From these it can be seen that the proposed system appears to be at least as stringent as the current carcase monitoring program for TVC.

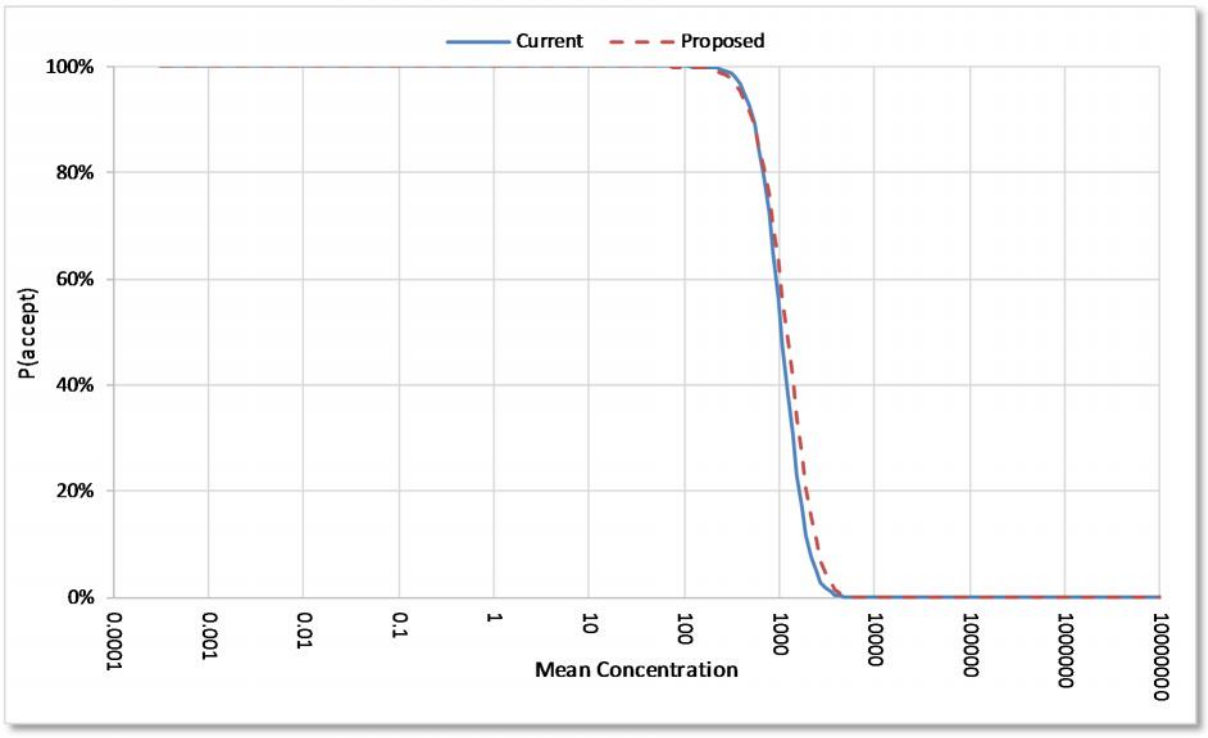

Figure 9: Comparison of OC Curves for TVC under current (cold-boned bovine carcases, n=15, c=3, m=3 (=log 1000), M=4.5 (=log 31,625) and proposed system (Table 10).

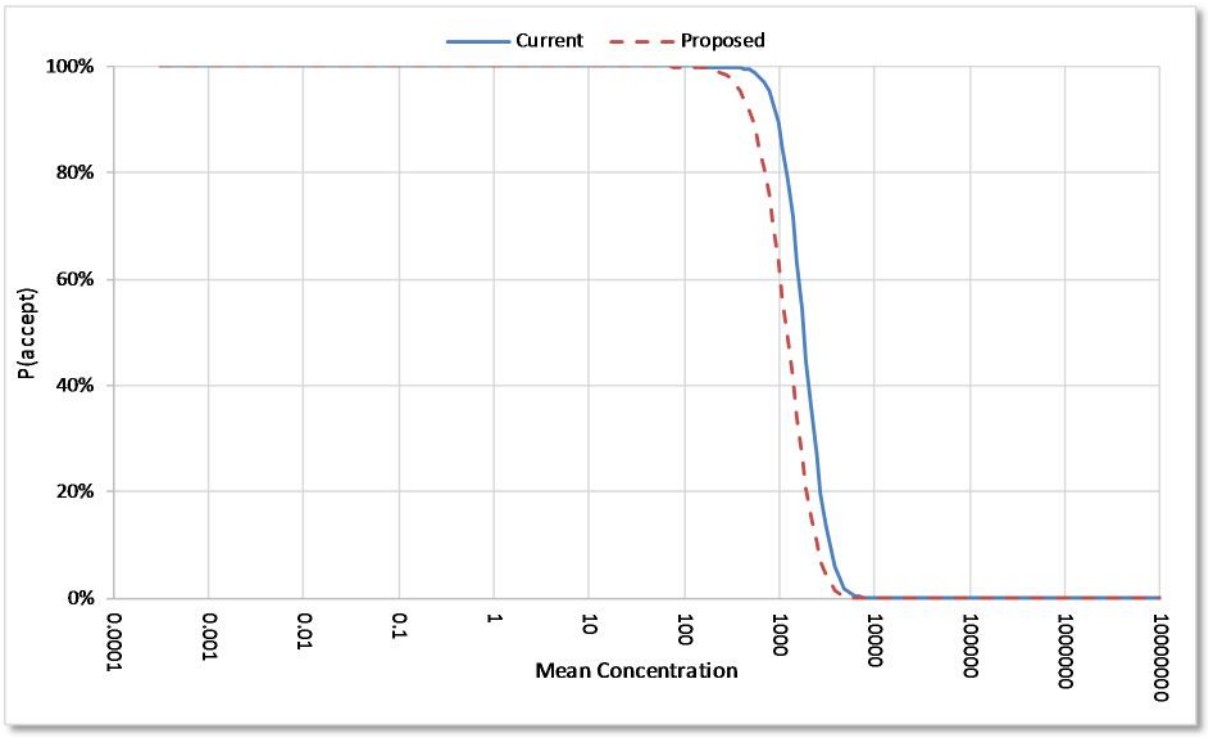

Figure 10: Comparison of OC Curves for TVC under current (ovine carcases, n=15, c=5, m=3 (=log 1000), M=4.5 (=log 31625)) and proposed system (Table 10).

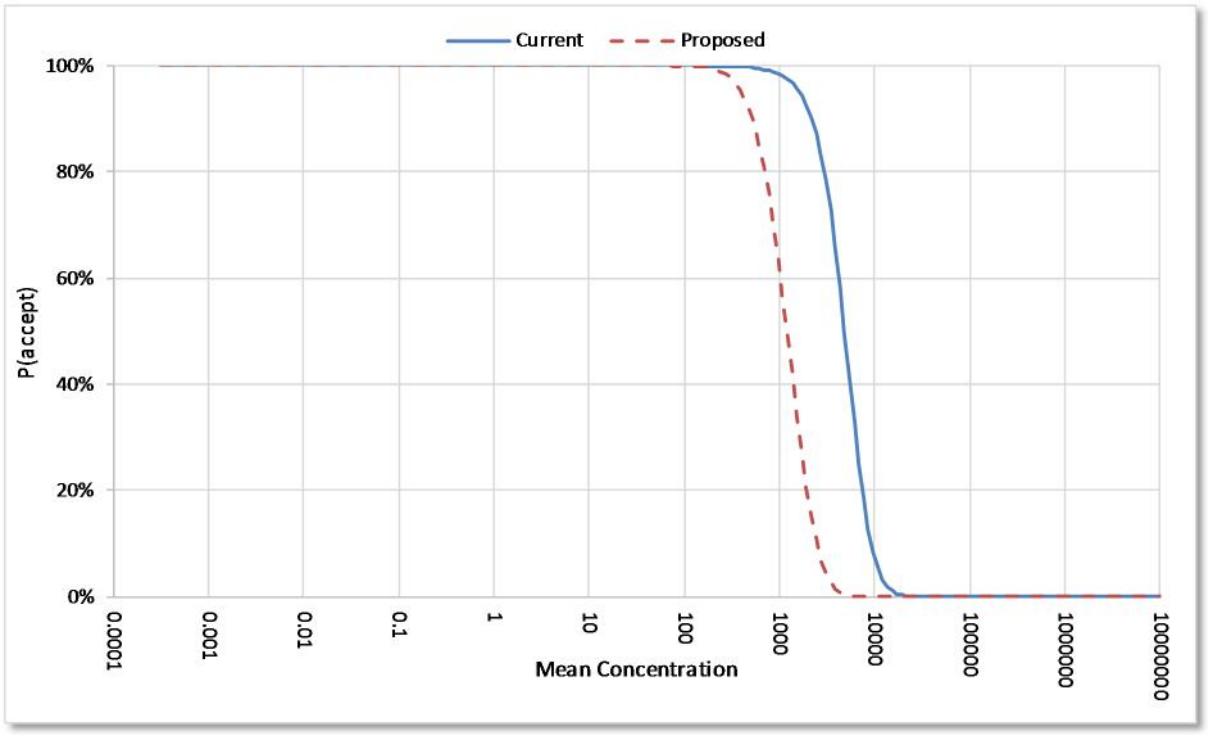

Figure 11: Comparison of OC Curves for TVC under current (porcine carcases, n=15, c=5, m=3.5 (=log 3162), M=4.5 (=log 31625)) and proposed system (Table 10).

E. coli

Below are shown the OC curves comparing the current and alternate systems for cold-boned bovine (Figure 12), ovine (Figure 13) and porcine carcases (Figure 14); the criteria for cold-boned bovine carcases were used as those for hot-boned carcases are less stringent (i.e. curve is to the right). From these it can be seen that the proposed system appears to be less stringent for bovines, but more stringent for ovines and porcines than the current carcase monitoring program for *E. coli*. Clearly, the current bovine requirements are very stringent, by virtue of the very low m limit (i.e. non-detection of *E. coli*).

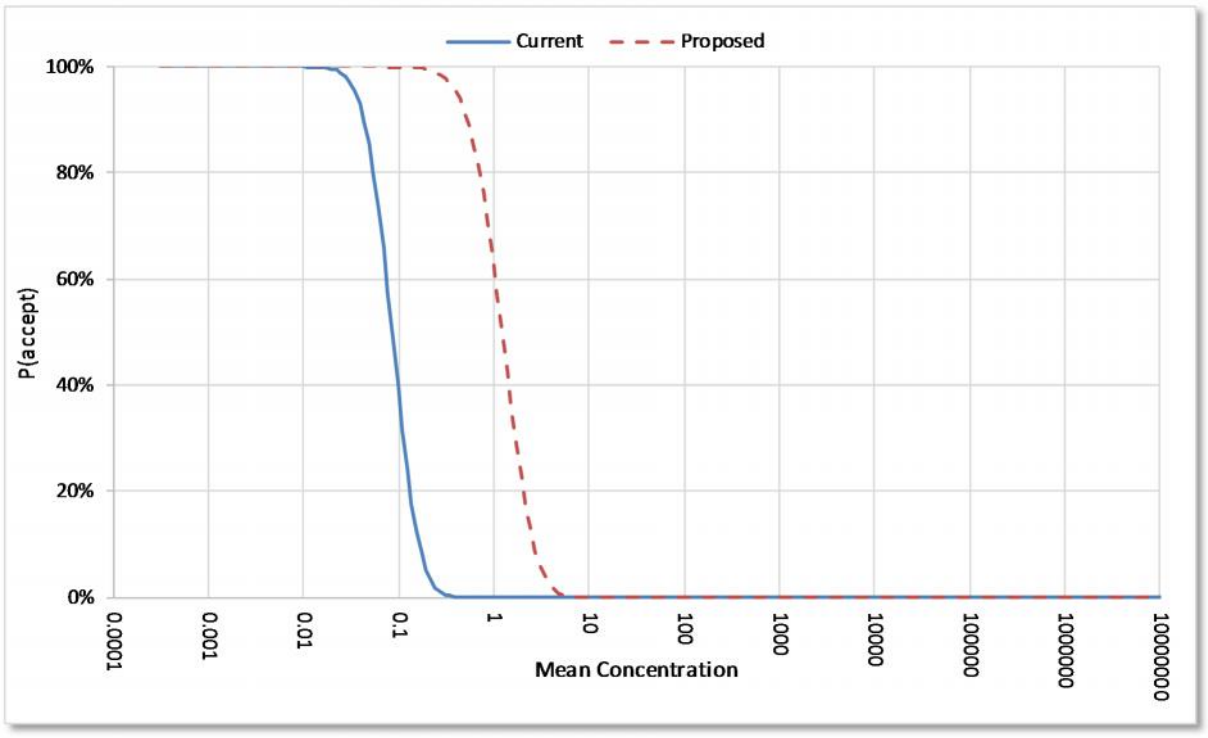

Figure 12: Comparison of OC Curves for E. coli *under current (cold-boned bovine, n=15, c=3, m=-1.1 (=log 0.08), M=1.3(=log(20))) and proposed system (Table 10).*

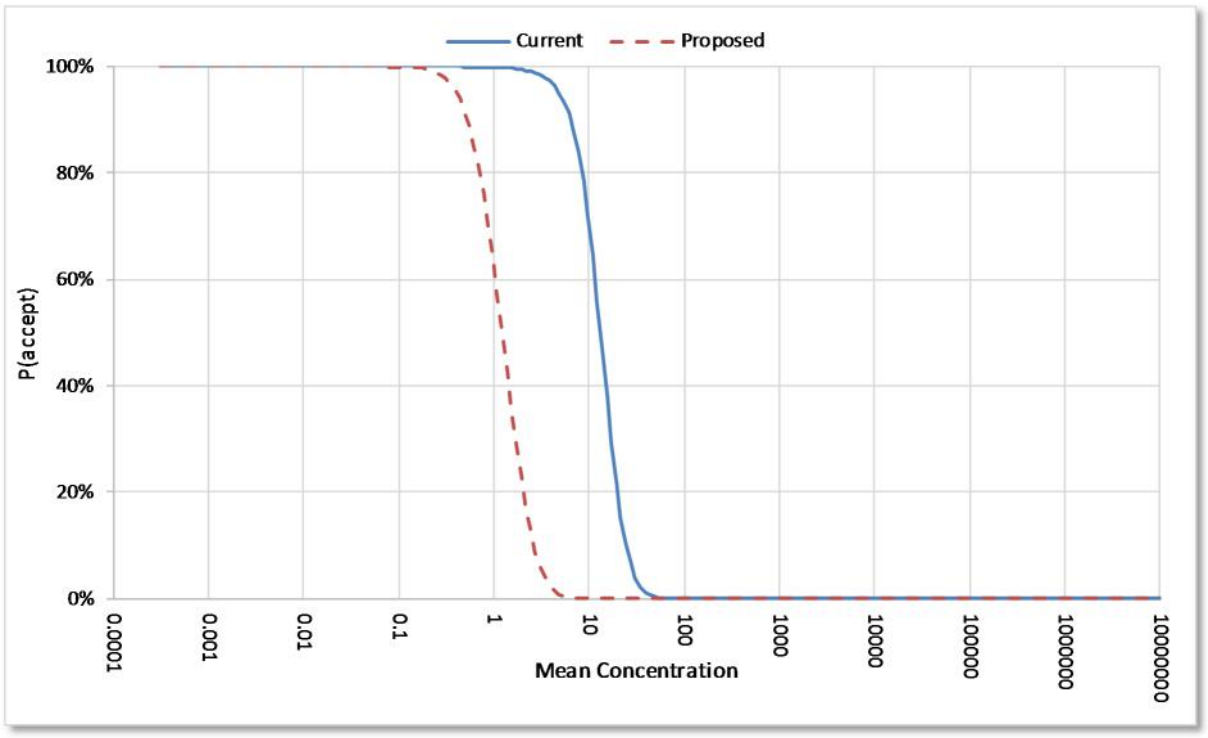

Figure 13: Comparison of OC Curves for E. coli *under current (ovine, n=15, c=7, m=0.7 (=log(5)), M=2 (=log 100)) and proposed system (Table 10).*

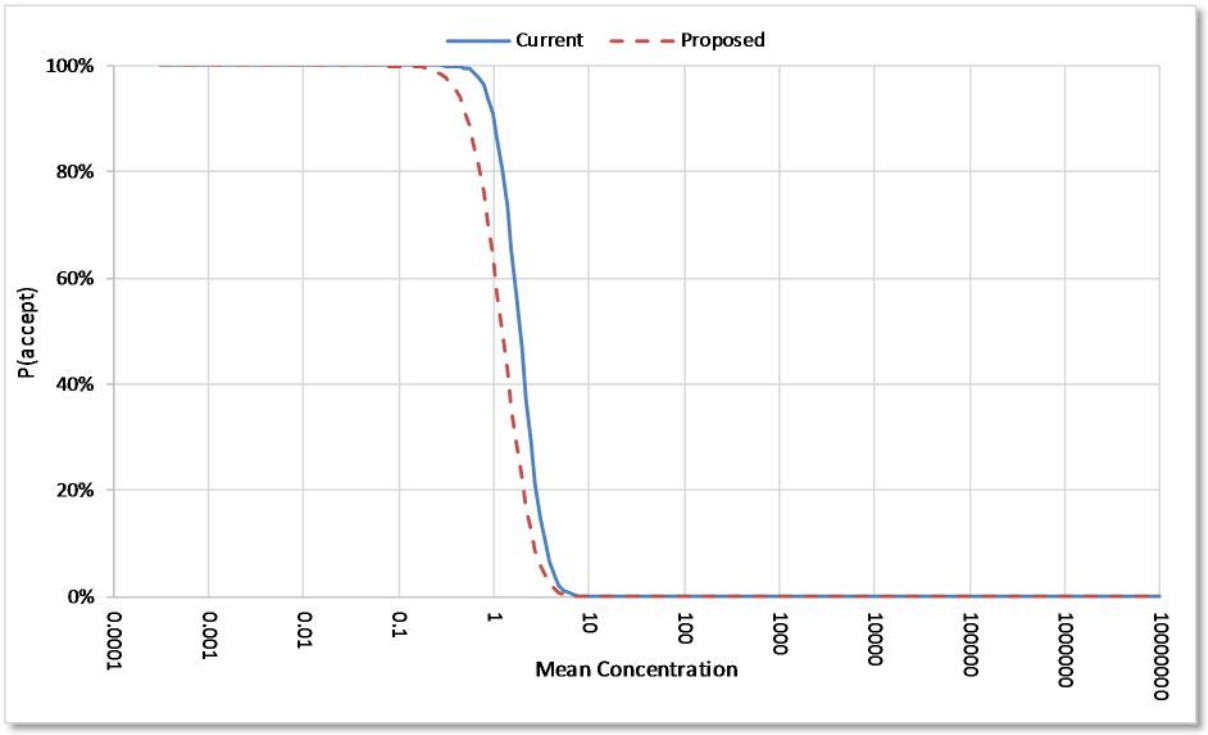

Figure 14: Comparison of OC Curves for E. coli *under current (porcine, n=15, c=5, m=0 (=log 1), M=2 (=log 100)) and proposed system (Table 10).*

Objective 1a: Assess the effectiveness of the proposed revised PHI system by collecting baseline data from beef, sheep and pork establishments to establish/revise limits for modified Meat Hygiene Assessment (MHA) for carcases, bulk meat, primals and offals.

Establishments' trial data

During the 13 months in which data were gathered, more than 1.6 million visual assessment results were entered into the SARDI database (Table 15).

Table 15: Visual assessment data submitted by Plants A-L from October 2017 – October 2018.

Establishment	Carcases	Bulk meat	Primals	Offals	Total
Beef					
A	10,412	11,721	6,733	38,264	**67,130**
B	7,660	0	0	122,420	**130,080**
C	30,645	30,171	11,140	173,090	**245,046**
D	35,060	39,569	15,494	152,161	**242,284**
E	48,328	7,715	13,457	107,148	**176,648**
F	15,051	22,201	15,990	57,545	**110,787**
Sheep					
G	31,042	7,120	2,880	22,020	**63,062**
H	17,455	0	0	40,740	**58,195**
I	184,243	7,145	10,450	101,815	**303,653**
Pigs					
J	38,963	25,779	8,040	18,284	**91,066**
K	35,199	16,323	5,477	29,370	**86,369**
L	22,102	8,655	14,500	25,960	**71,217**
Total	476,160	176,399	104,161	888,817	**1,645,537**

There were considerable differences in the number of visual checks completed between establishments, influenced by the number of product lines, customer requirements or management decisions to use more intensified checking. By contrast, some establishments have been able to negotiate reduced monitoring frequency as part of their Approved Arrangements, based on good historical performance.

Unlike for microbiological testing, the requirements for visual hygiene are less prescriptive and open to interpretation e.g. determining what constitutes a lot, intensity of checking, what product lines are combined or checked separately.

Each establishment's visual assessment data were analysed by constructing temporal charts for carcases and end products produced at that establishment; a typical output is presented in Figure 15 for Establishment D, where:

- There were no obvious seasonal effects on visual assessment scores.
- Carcase, bulk meat, primal and offal daily average scores were generally below the limits of 1.5, 0.5, 0.5 and 0.5 respectively.

The daily average scores in Figure 15 were calculated from all the checks completed using the current frequency of checking. Note however, that for the current CMA system, acceptable performance is not based on an average score (as it is for carcase and offal) but a more complicated moving window system for minor, major and critical defects. As part of the proposal for an alternate CMA system it

was suggested that CMA could also be based on an average defect score, thus harmonising the various components of visual assessment.

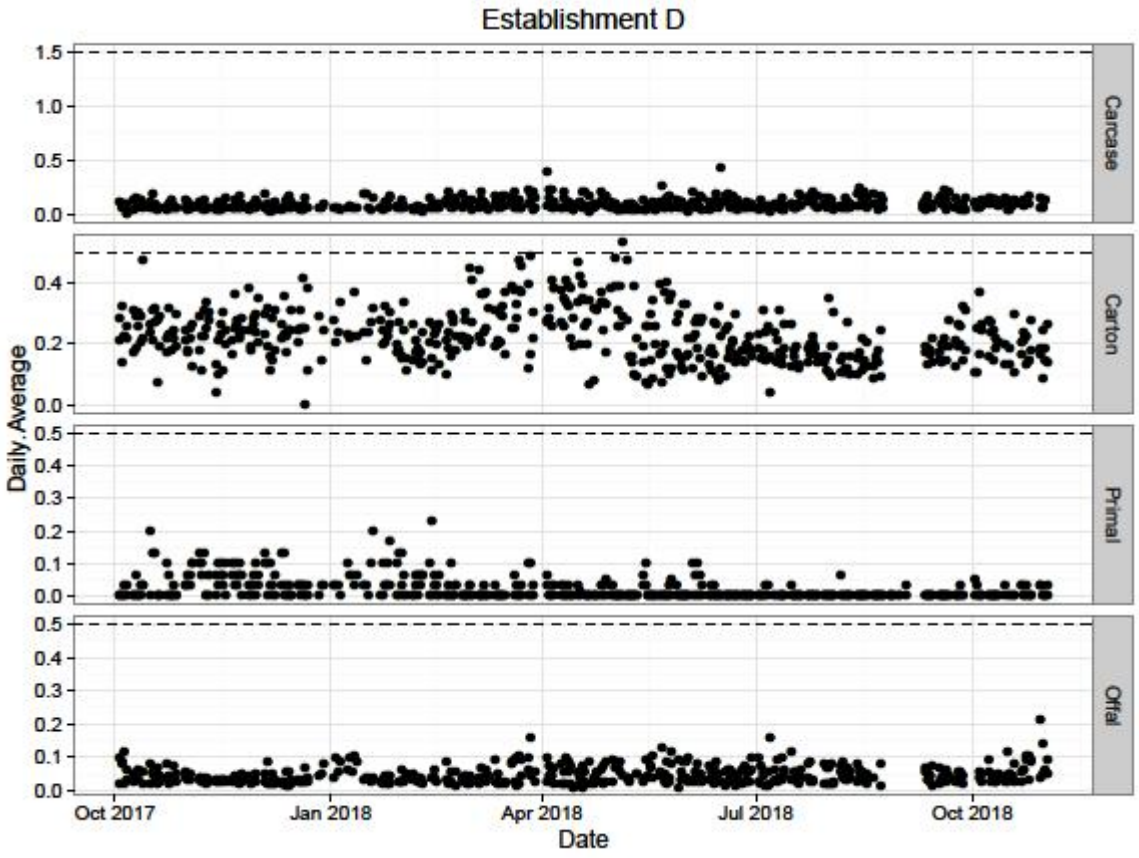

Figure 15: Daily average defect score at Establishment D during October 2017 to October 2018 – dashed lines represent limits of 1.5, 0.5, 0.5 and 0.5 respectively for carcases, bulk meat, primals and offal.

A compendium of the visual assessment profiles of carcases and end products of all twelve participating establishments is presented in Appendix 6.

Assessment of visual hygiene monitoring performance

Visual inspection of end products is an important part of assessing product wholesomeness. However, the current MHA and CMA requirements are intensive and different scoring systems are used for slaughter floor/boning room MHA, offal MHA and bulk meat product.

In AMPC 2017-1068, it was proposed to:

1. Focus on those aspects that pose a potential microbial contamination risk – for example, monitoring for manufacturing defects could be removed.
2. Harmonise the scoring systems across carcases, bulk meat, primals and offal to all be based on daily average scores. Utilise current average daily limits of 1.5 and 0.5 for carcases and offal, and propose similar limits to offal for bulk and primal products.

Reduce and harmonise the frequency of visual defect monitoring as shown in

3. Table 16, given the overall good performance of industry. These are suggested as a minimum, but establishments should have the option to intensify their monitoring for different product lines.

Table 16: Frequency of MHA for carcases, bulk meat, primals and offal.

Category	Samples per set	Sets per day	Product types per category
Carcase (SF)	10	3	
Bulk meat	10	3	Sample sets are rotated randomly across product types.
Primals	10	3	Sample sets are rotated randomly across product types.
Offal	10	3	Sample sets are rotated randomly across product types.

As under the current MHA system, the scoring would be weighted according to severity i.e. Minor = 1, Major = 3, Critical = 6 and Zero Tolerances (ZTs) = 10. ZTs would also trigger alerts under the alternative system, as they do under the current system.

The results of the trial were discussed on several occasions with each participating establishment, an industry expert panel and the Reference Panel, but a consensus on an alternative system could not be obtained. Among the aspects which could not be resolved were:

- Currently, defect severities differ between carcase and offal types and thus should be reviewed e.g. a bruise of 2-5 cm on carcases is a minor defect while for offal it is a major defect.
- Should manufacturing defects be removed from assessment criteria as proposed by DAWR (Pearse *et al.* 2012) and, if so, how would this affect limits?
- What should happen in the case of an Alert (e.g. a zero tolerance defect or exceeding the limit) under a revised system? Currently, this initiates defrost re-inspection procedures.
- Could the current requirements be amended to allow reduced inspection frequencies in line with good performance on specific products? For example, some products result in very few, if any, defects – could inspection frequencies be reduced on that basis, and increased when a problem is found? What effect should this have on defrost re-inspections?

As a result, this project has identified the need for a more comprehensive review of visual inspection, including which defects should be monitored as part of regulatory compliance, a review of defect severity criteria (definitions of a Minor, Major and Critical) and practical elements of what action should be taken in the event of an Alert.

Data collected as part of the trial would be invaluable in informing this review.

This recommendation for a full review of MHA/CMA supports the findings of previous work by DAWR (Pearse *et al.* 2012).

This section summarises and analyses the trial results based on dividing visual defect categories into three major groups – manufacturing, contamination and pathology as follows:

Table 17: Allocation of visual defect categories into broad groups, collectively for MHA, CMA, primals and offal.

Manufacturing	Contamination	Pathology
Bruises and blood clots	Rail dust, specks, hide and wool dust	Pathology
Seeds	Smears and stains (inc. bile, oil and grease), discoloured areas	
Bone fragments	Hair and wool strands	
Detached cartilage and ligaments	Hair and wool clusters, hide, scurf and toenails	
Scar tissue	Foreign objects & extraneous tissue	
Other	Off condition	

Appendix 7 contains graphs of the proportion of each visual defect category to the total number of defects (regardless of severity) for each species (beef, sheep, pigs) and for carcass bulk meat, primal and offals.

Summaries of the number of minors, majors, criticals under each broad defect category and ZTs, as well as the number of alerts under the current and proposed systems for carcases, bulk meat, primals and offal are given in Table 18 to

Table 21:.

	Offal								
cks	Minors		Majors		Criticals			ZTs	
	Manufacturing	Contamination	Manufacturing	Contamination	Manufacturing	Contamination	Pathology		Curre syste
264	14 (0.04)	1,034 (2.70)	0	1 (<0.01)	0	0	0	0	
420	195 (0.16)	978 (0.80)	106 (0.09)	209 (0.17)	10 (0.01)	7 (<0.01)	109 (0.09)	5	
090	652 (0.38)	2,649 (1.53)	15 (0.01)	54 (0.03)	1 (<0.01)	5 (<0.01)	0	191	
161	363 (0.24)	3,365 (2.21)	111 (0.07)	806 (0.53)	7 (<0.01)	38 (0.03)	15 (0.01)	3	
148	97 (0.09)	2,171 (2.03)	1 (<0.01)	19 (0.02)	0	3 (<0.01)	0	1	
545	10 (0.02)	1,316 (2.29)	6 (0.01)	19 (0.03)	10 (0.02)	0	0	7	
020	1 (<0.01)	1 (<0.01)	0	0	1 (<0.01)	0	1	0	
740	78 (0.19)	173 (0.42)	7 (0.02)	92 (0.23)	1 (<0.01)	9 (0.02)	252 (0.62)	0	
815	212 (0.21)	541 (0.53)	0	2 (<0.01)	0	0	2 (<0.01)	0	
284	29 (0.16)	423 (2.31)	2 (0.01)	14 (0.08)	0	0	3 (0.02)	0	
370	390 (1.33)	1,332 (4.54)	22 (0.07)	108 (0.4)	3 (0.01)	13 (0.04)	6 (0.02)	0	
960	71 (0.27)	390 (1.50)	7 (0.03)	74 (0.29)	1 (<0.01)	1 (<0.01)	0	0	

The “Proposed Alerts” column represents a sampling frequency as per

Table 16 and the comparison of a daily average score to 1.5, 0.5, 0.5 and 0.5 for carcases, bulk meat, primals and offal, respectively.

It is also important to note that ZTs would trigger alerts under the alternative system, as they do under the current system, and are in addition to the alerts in the "Current Alerts" and "Proposed Alerts" columns.

Key findings of the analysis are:

- An extremely large number of visual checks were carried out by each plant, with the number of checks varying radically across establishments, with no relationship to the number of animals being processed.
- For carcases:
  - The majority of defects were minor and there were very few zero tolerance defects.
  - The quantity of minor defects recorded varied widely between establishments, from beef Establishment D (5.9%) to Establishment G (78.2%).
  - Records of pathology also varied widely with Establishment E and I (the same establishment) being responsible for 76% of all pathology detections.
- For CMA minor defects accounted for 99% of total defects, with manufacturing defects far outweighing contamination related defects.
- For primals there were very few recorded defects, again with 99% being minor.
- Similarly, for offals, most records were for Minor defects, with the exception of Establishments E and I (the same establishment, different species) where 93% of pathology defects were recorded, and Establishment C, which recorded 191 ZTs (all for mountain chains).
- Overall visual requirement limits are breached very infrequently (see also Appendix 6).
- Under simulation of the alternative system, three establishments would have one alert every ten years from carcase MHA.
- By contrast, for CMA under the alternative system, the use of a daily average would have resulted in more frequent failures for some plants, the majority of which involved manufacturing defects.
- Visual checks for primals, which are not a requirement under the current system, would result in occasional alerts under the alternative system.

These findings clearly support those of the DAWR review (Pearse, 2012): "*Carton meat assessment and offal product and process monitoring are not adding value to the MHA data set but are obviously important aspects for the company to monitor; these activities will be deregulated and removed from MHA*".

Table 18: Summary of defects (minors/majors/critical and manufacturing/contamination/pathology), ZTs and alerts under the current and proposed systems for carcases from the participating trial establishments; numbers in parentheses indicate the corresponding percentage.

	Carcases										
Establishment	**Checks (#)**	**Minors**		**Majors**		**Criticals**			**ZTs**	**Alerts**	
		Manufacturing	Contamination	Manufacturing	Contamination	Manufacturing	Contamination	Pathology		Current system	Proposed system
A	10,412	12 (0.12)	1,363 (13.1)	74 (0.71)	1 (0.01)	0	1 (0.01)	1 (0.01)	5	0	0
B	7,660	64 (0.84)	1,715 (22.4)	44 (0.57)	243 (3.17)	2 (0.03)	43 (0.56)	16 (0.21)	7	0	0.1
C	30,645	83 (0.27)	3,269 (10.7)	52 (0.17)	165 (0.54)	0	4 (0.01)	12 (0.04)	5	0	0
D	35,060	62 (0.18)	2,003 (5.71)	26 (0.07)	316 (0.90)	1 (<0.01)	21 (0.06)	31 (0.09)	0	0	0
E	48,328	1,466 (3.03)	18,031 (37.3)	43 (0.09)	1,339 (2.77)	0	25 (0.05)	165 (0.34)	3	0	0.1
F	15,051	35 (0.23)	1,795 (11.9)	41 (0.27)	276 (1.83)	1 (0.01)	3 (0.02)	0	5	0	0
G	31,042	3,562 (11.5)	20,700 (66.7)	10 (0.03)	64 (0.21)	1 (0.003)	4 (0.01)	11 (0.04)	2	0	0
H	17,455	204 (1.17)	2,085 (12.0)	29 (0.17)	373 (2.14)	3 (0.02)	29 (0.17)	207 (1.37)	14	0	0.1
I	184,243	5,092 (2.76)	69,954 (38.0)	418 (0.23)	4,218 (2.29)	26 (0.01)	109 (0.06)	465 (0.25)	1	0	0
J	38,963	61 (0.16)	4,258 (10.9)	16 (0.04)	422 (1.08)	0	48 (0.12)	62 (0.16)	7	0	0
K	35,199	2,574 (7.31)	13,557 (38.5)	49 (0.14)	245 (0.70)	3 (0.01)	8 (0.02)	50 (0.14)	5	0	0
L	22,102	914 (4.14)	7,215 (32.6)	39 (0.18)	619 (2.80)	2 (0.01)	22 (0.10)	40 (0.18)	2	0	0

Table 19: Summary of defects (minors/majors/critical and manufacturing/contamination/pathology), ZTs and alerts under the proposed systems for CMA from the participating trial establishments; numbers in parentheses indicate the corresponding percentage.

	CMA									
Establishment	**Checks (#)**	**Minors**		**Majors**		**Criticals**			**ZTs**	**Alerts**
		Manufacturing	Contamination	Manufacturing	Contamination	Manufacturing	Contamination	Pathology		Proposed system
A	11,721	1,980 (16.9)	140 (1.19)	14 (0.12)	0	0	0	0	1	0
B	NA									
C	30,171	4,557 (15.1)	854 (2.83)	8 (0.03)	1 (<0.01)	2 (0.01)	1 (<0.01)	9 (0.03)	3	0
D	39,569	9,103 (23.0)	30 (0.08)	2 (0.01)	0	0	0	0	0	1.6
E	7,715	691 (8.96)	974 (12.6)	1 (0.01)	14 (0.18)	49 (0.64)	0	0	0	17.4
F	22,201	1,120 (5.04)	649 (2.92)	2 (0.01)	2 (0.01)	0	0	2 (0.01)	1	0
G	7,120	254 (3.57)	376 (5.28)	19 (0.27)	7 (0.10)	0	0	0	0	0
H	NA									
I	7,145	321 (4.49)	1,183 (16.6)	4 (0.06)	1 (0.01)	11 (0.15)	0	0	1	2.2
J	25,779	3,983 (15.5)	647 (2.51)	6 (0.02)	4 (0.02)	2 (0.01)	0	3 (0.01)	2	2.9
K	16,323	2,149 (13.2)	2,625 (16.1)	45 (0.28)	3 (0.02)	9 (0.06)	2 (0.01)	6 (0.04)	0	2.0
L	8,655	21 (0.24)	247 (2.85)	0	0	0	0	0	0	0

Table 20: Summary of defects (minors/majors/critical and manufacturing/contamination/pathology), ZTs and alerts under the current and proposed systems for primals from the participating trial establishments; numbers in parentheses indicate the corresponding percentage.

	Primals									
Establishment	**Checks (#)**	**Minors**		**Majors**		**Criticals**			**ZTs**	**Alerts**
		Manufacturing	Contamination	Manufacturing	Contamination	Manufacturing	Contamination	Pathology		Proposed system
A	6,733	52 (0.77)	11 (0.16)	0	0	0	0	0	0	0
B	NA									
C	11,140	4 (0.04)	7 (0.06)	0	2 (0.02)	0	0	1 (0.01)	0	0.1
D	15,494	192 (1.24)	91 (0.59)	4 (0.03)	0	1 (0.01)	0	0	0	0.1
E	13,457	148 (1.10)	187 (1.39)	8 (0.06)	2 (0.01)	0	0	0	0	0
F	15,990	0	50 (0.31)	0	4 (0.03)	0	0	0	5	0.7
G	2,880	34 (1.18)	148 (5.14)	0	2 (0.07)	0	0	0	0	0.6
H	NA									
I	10,450	80 (0.77)	367 (3.51)	2 (0.02)	3 (0.03)	0	0	2 (0.02)	0	0.1
J	8,040	125 (1.55)	22 (0.27)	0	0	0	0	0	0	0
K	5,477	204 (3.72)	438 (8.00)	0	1 (0.02)	0	0	1 (0.02)	0	3.4
L	14,500	0	75 (0.52)	0	0	0	0	0	0	0

Table 21: Summary of defects (minors/majors/critical and manufacturing/contamination/pathology), ZTs and alerts under the current and proposed systems for offals from the participating trial establishments; numbers in parentheses indicate the corresponding percentage.

	Offal										
Establishment	**Checks (#)**	**Minors**		**Majors**		**Criticals**			**ZTs**	**Alerts**	
		Manufacturing	Contamination	Manufacturing	Contamination	Manufacturing	Contamination	Pathology		Current system	Proposed system
A	38,264	14 (0.04)	1,034 (2.70)	0	1 (<0.01)	0	0	0	0	0	0
B	122,420	195 (0.16)	978 (0.80)	106 (0.09)	209 (0.17)	10 (0.01)	7 (<0.01)	109 (0.09)	5	0	0.8
C	173,090	652 (0.38)	2,649 (1.53)	15 (0.01)	54 (0.03)	1 (<0.01)	5 (<0.01)	0	191	0	1.7
D	152,161	363 (0.24)	3,365 (2.21)	111 (0.07)	806 (0.53)	7 (<0.01)	38 (0.03)	15 (0.01)	3	0	2.2
E	107,148	97 (0.09)	2,171 (2.03)	1 (<0.01)	19 (0.02)	0	3 (<0.01)	0	1	0	0
F	57,545	10 (0.02)	1,316 (2.29)	6 (0.01)	19 (0.03)	10 (0.02)	0	0	7	0	0
G	22,020	1 (<0.01)	1 (<0.01)	0	0	1 (<0.01)	0	1	0	0	0
H	40,740	78 (0.19)	173 (0.42)	7 (0.02)	92 (0.23)	1 (<0.01)	9 (0.02)	252 (0.62)	0	0	3.8
I	101,815	212 (0.21)	541 (0.53)	0	2 (<0.01)	0	0	2 (<0.01)	0	0	0
J	18,284	29 (0.16)	423 (2.31)	2 (0.01)	14 (0.08)	0	0	3 (0.02)	0	0	0.1
K	29,370	390 (1.33)	1,332 (4.54)	22 (0.07)	108 (0.4)	3 (0.01)	13 (0.04)	6 (0.02)	0	0	0.1
L	25,960	71 (0.27)	390 (1.50)	7 (0.03)	74 (0.29)	1 (<0.01)	1 (<0.01)	0	0	0	0.1

Objective 2: Assess the performance, ease of use and understanding of the revised system by DAWR on-plant veterinary staff and establishment quality assurance staff.

The trial protocols and revised visual and microbiological monitoring systems were explained and discussed on three occasions with each plant's quality assurance staff and management: at inception, at the midway point and at the end of the trial. On-plant veterinary staff attended some discussions.

On two of these three occasions, the monitoring spreadsheet (see Objective 3) was demonstrated. Staff supported inclusion of end-product testing (bulk meat, primals and offal) as part of the regulatory monitoring program and the reporting tool was well received both for its ease of use and for its real-time impact.

Objective 3: Design a timely reporting and responding system based on recording and reporting spreadsheets with clearly identified performance criteria.

An Excel spreadsheet was developed for entering all data collected as part of this project. The spreadsheet contains separate data entry sheets for carcases, bulk meat, primals and offal, for both microbiological and visual results. In addition, a summary sheet was included to summarise all monitoring results for any given month and to display Alerts on a real-time basis i.e. as soon as the data had been entered.

Objective 4: Provide information and data to assist the DAWR to develop equivalence submissions for international markets.

A series of position papers were prepared which may be useful for establishments and the DAWR to frame a proposal to overseas countries for a change in the way Australia monitors products in process and products as they enter the marketplace.

Material in these documents was drawn largely from work completed as part of three AMPC projects:

- "*Process Control Monitoring – Is there a better way?"* (AMPC Project 2017-1068)
- "*Process Monitoring for the Australian meat industry – a comparative industry trial*" (AMPC Project 2018-1070)
- "*Research and development in the Australian red meat industry: its impact on food safety and shelf-life*" (AMPC Project 2018-1086).

The individual position papers are:

1. The modern Australian slaughter and dressing system
2. Carcase hygiene – the National Carcase Microbiological Monitoring Program
3. Global comparisons – Australian meat in international trade
4. Risk of STEC illness in Australia from meat consumption

These position papers are presented in Appendix 8.

7.0 CONCLUSIONS/RECOMMENDATIONS

Regarding visual checking, it is concluded that:

1. Establishments do a huge amount of visual testing of carcases and of final products, primals, bulk meat and offals.
2. The number of checks varies widely between establishments and is not directly related to the volume of production.
3. Overall, visual hygiene performance was very good and limits were breached very infrequently.

4. Despite numerous meetings between industry and representatives and the project Reference Panel no consensus could be reached on what might comprise an alternative system for visual monitoring.

Accordingly it is recommended that a comprehensive review be undertaken of MHA and CMA, including which defects should be monitored as part of regulatory compliance; defect severity criteria (definitions of a Minor, Major and Critical) and practical elements of what action should be taken in the event of an Alert.

Considering microbiological testing data gathered by the twelve participating establishments, it is concluded that:

1. The microbiological profile of bovine, ovine and porcine carcases confirms the substantial improvements recorded over recent decades by the ESAM database and by national baseline surveys.
2. The microbiology of bulk meat, primals and offals conforms well with limits imposed by other countries (e.g. New Zealand) and by commerce (e.g. supermarkets).
3. A proposed system based on testing carcases, bulk meat, primals and offals would provide better information to establishments and their customers.

Accordingly it is recommended that the industry and the department pursue with overseas markets the possibility of amending the present agreed system based solely on carcase monitoring to include bulk meat, primals and offals.

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