MEAT & LIVESTOCK AUSTRALIA

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Managing the cold chain and shelf life of chilled vacuum packed beef and sheep meat

Contents

DISCLAIMER

Meat & Livestock Australia acknowledge the matching funds provided by the Australian Government to support the research and development detailed in this publication.

1. Introduction

Shelf life (or storage life) has always been important in the meat trade, and is becoming increasingly so, as Australian retailers and importers in overseas countries request information to substantiate company claims about how long their products will remain saleable and increase in export activities such as retail ready.

This document will focus on products in three types of packaging and transport modes:

1. Carcases and vacuum packed primals air freighted to destinations
2. Vacuum packed primals and primal cuts transported by sea freight
3. Retail ready vacuum skin packed (VSP) via air freight

*Other types of packaged primals, carcases and quarters are excluded as their shelf life cannot be calculated by the shelf life model.

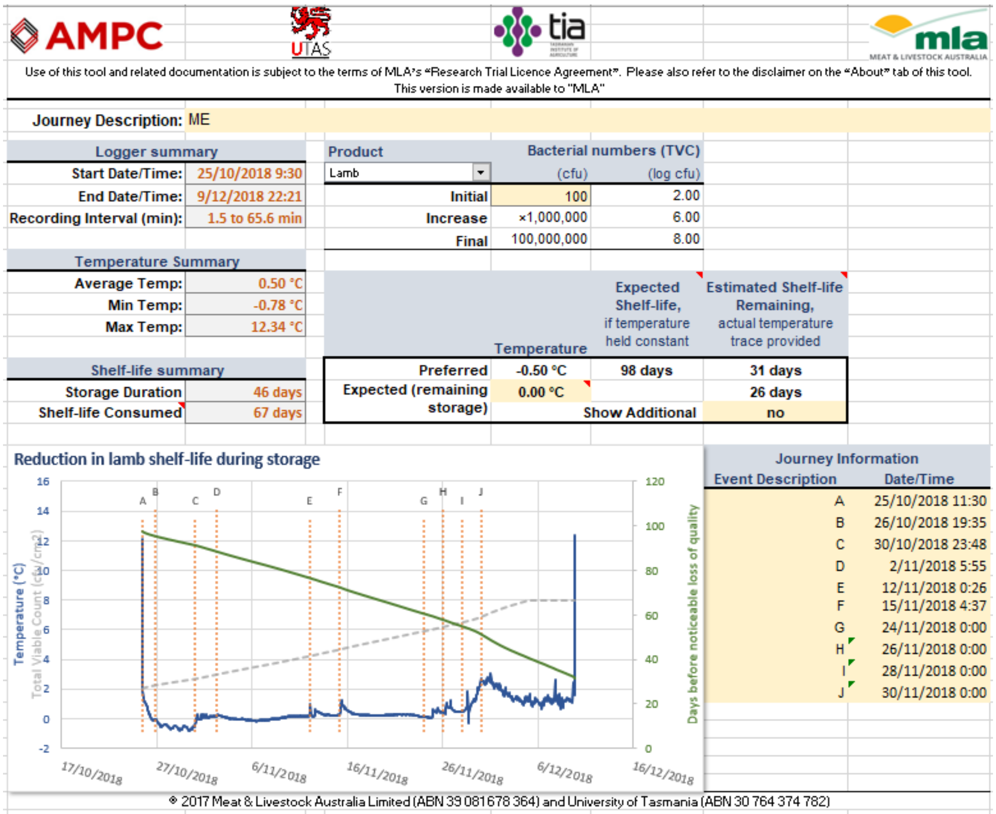
For many years there was anecdotal evidence from the trade that Australian vacuum packaged primals had longer storage lives in commerce compared with product from competing countries, with 100 days (~14 weeks) at -1°C quoted. The evidence for achieving the long shelf life of Australian beef and sheep meats is discussed in MLA publication, *Shelf life of Australian red meat (2nd edition).* With storage temperature of -0.5°C vacuumed beef primals can achieve 160 days and lamb achieve 90 days.

There are various factors which contribute to the shelf life of beef and lamb primals, such as ultimate pH, processing conditions (hygiene, ambient temperature) and good quality packaging/seal.

In vacuum packed product, maximum bacterial counts can be reach around 7 to 8 log cfu/cm^2 well before the shelf life has ended. Thus, these high counts are usually found in product before the end of shelf life, and does not predict poor smell, odour or taste of the product. The harmless nature of these bacteria is because in the case of vacuum-packed beef and lamb, the dominant microflora was composed of Lactic Acid Bacteria, and is not a reliable indicator for shelf life.

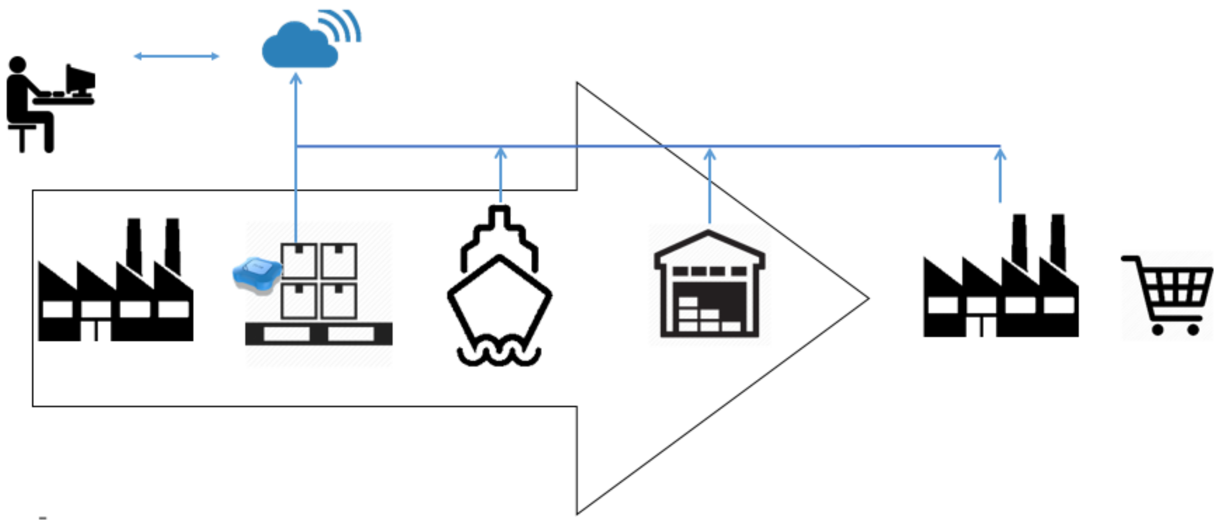
Temperature by far has the highest impact of overall shelf life of product. For every 1 degree the rate of shelf life decreased by about 30%. Controlling temperature gives the best insurance for a long shelf life. A short period of temperature abuse may not have a significant impact on your product - you can work this out with the help of the Shelf life prediction tool.

MLA in conjunction with University of Tasmania have developed a predictive tool which estimates shelf life of vacuum packed beef and sheep primals. The tool is described in *Shelf life of Australian red meat* and can be used to predict remaining shelf life providing you know the TVC at packing and the time:temperature record during storage. Once these parameters are entered into the model and either the lamb or beef is selected, predictions for TVCs and days remaining until detection of a strong odour on opening the pack can be predicted.



2. Understanding and tracking the whole cold chain performance using real time data loggers

Real time data loggers collect information similar to USB loggers with location and other measurements and will periodically send data to the cloud meaning you would not need to retrieve the logger to download, Appendix 2 will list the different logger companies available at the time this document was published. Because they remotely send data with time and location you can now directly correlate the data with certain part of the supply chain.

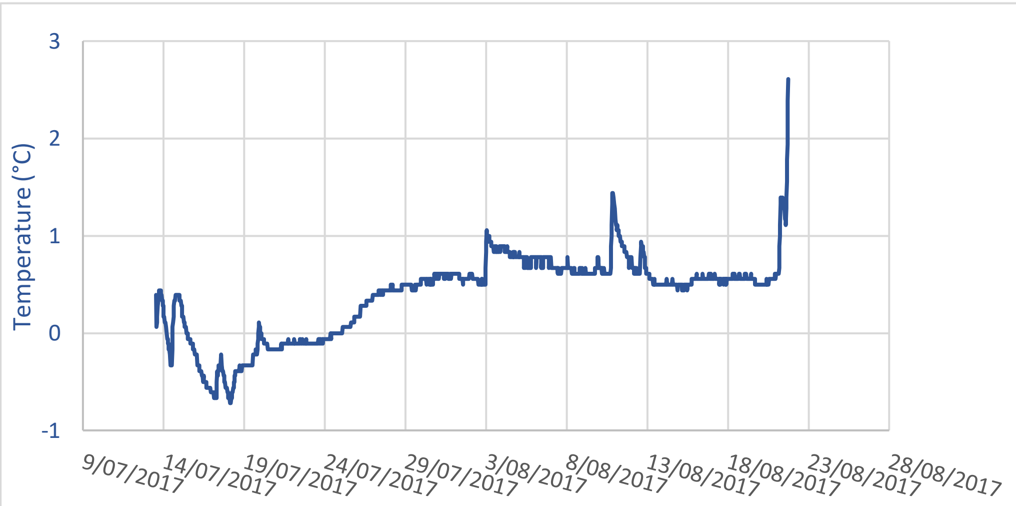


Real time loggers can be used to track carton within Australia, during shipment and/or to the wholesaler and end customers. It should be noted that the logger will not transmit when it is on open waters, or deep within the container being buried by other cartons or other containers.
It is recommended to put the carton with the loggers near the door for consistent data transmission at 1 hour recording interval and 4 hour transmission for best battery life. Also about 4 hours before arriving at port, loggers will transmit all the data that's been collected since it was last sent data.
For those whom want to know the difference in temperature within the container or how the packing method is impacting on your temperature, you can also put one logger in the front for comparison it is usually 1°C.

2.1. Sea shipments examples

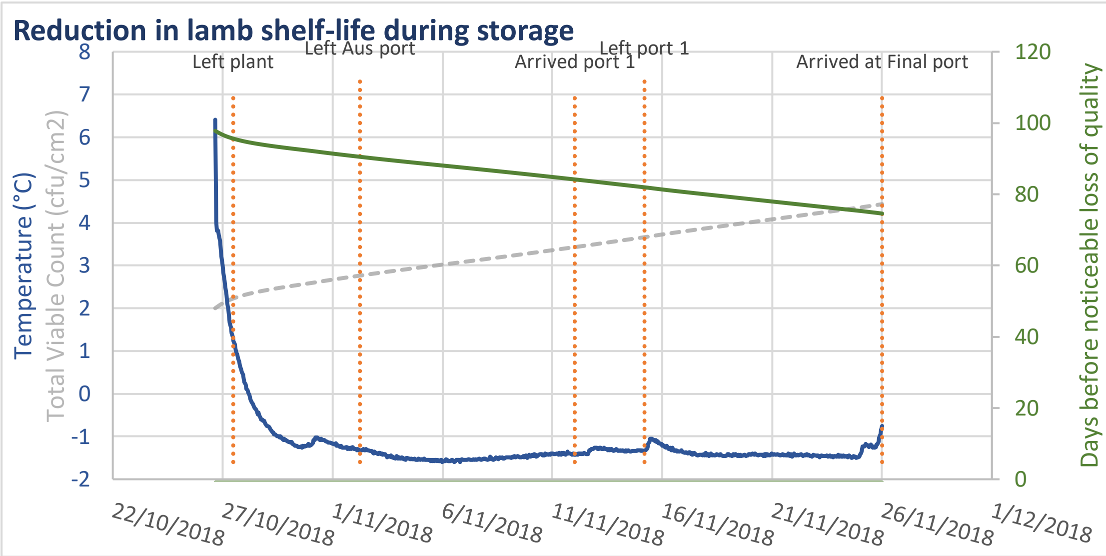
a) A usb logger example

A USB logger gives data of the temperature and time, however this won't be easily broken down to cold chain segments and we can only assume the spikes are during loading and unloading. The data is still useful to use when using the shelf life model to determine the shelf life remaining when arriving at customer's warehouse.



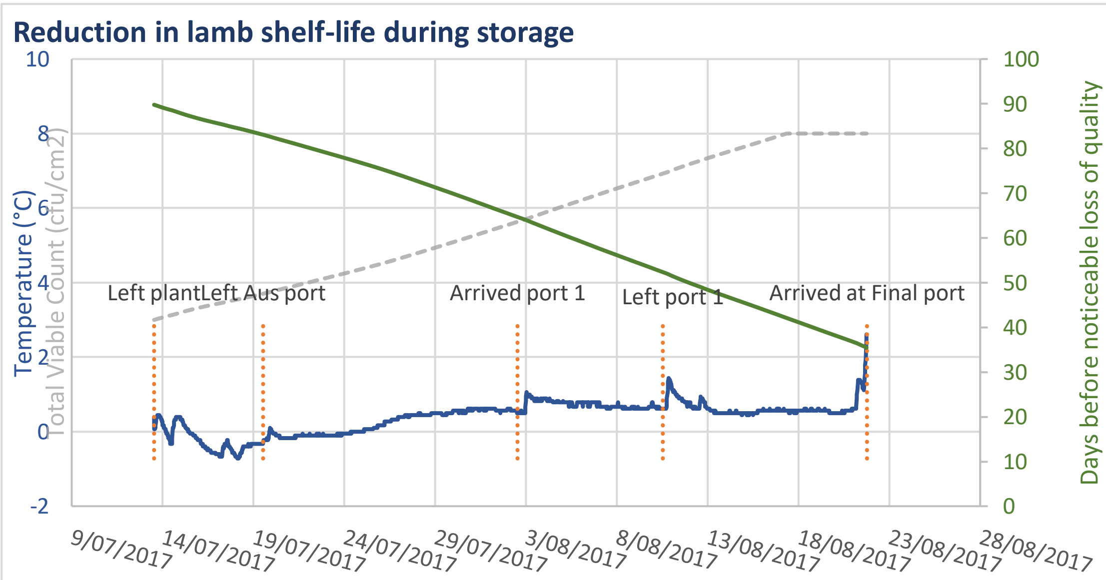
b) Middle East – a good trip

Using a real time logger, we can confidently locate where the temperatures spikes are occurring. This information is critical if the cold chain is unknown to you or you have experienced some issues on a regular basis. The shipment below shows a very good sea shipment, as majority of the journey it was below -0.5°C. Even after 30 days lamb product still has 72 days remaining if held at -0.5°C.



c) Middle East – a bad trip

Note that the average transport temperature is at 0.5°C (Which is considered good temperature), however due to the long time storage relative to a good shipment above, its HALF the Shelf life with 36 days remaining if held at -0.5°C when it customers receives the product.



d) Common trends, impact on shelf life and pit falls

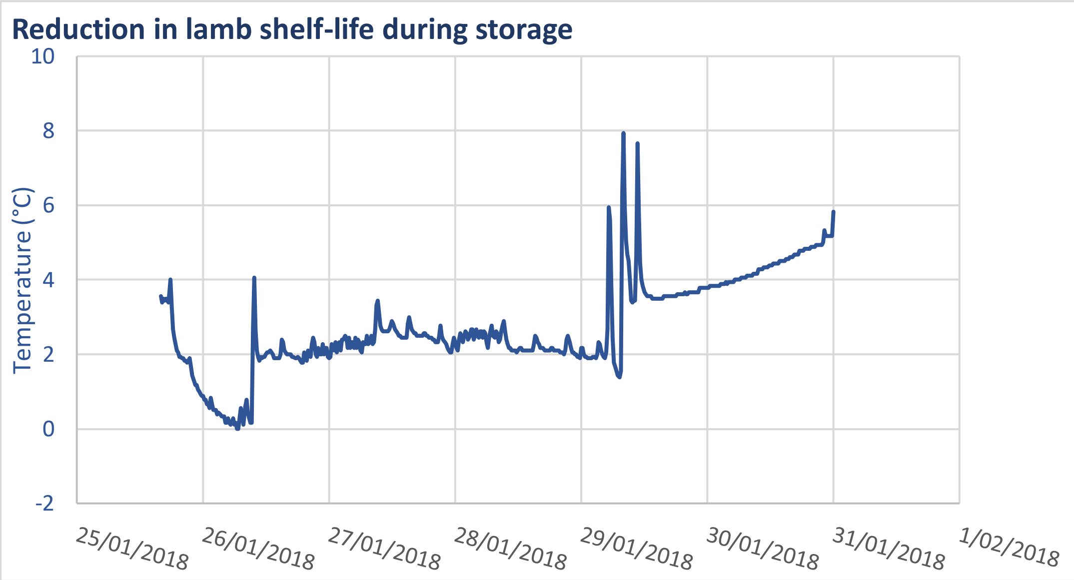
Long shipments at low temperature has more impact on shelf life for example 1°C can be up to 7 days different.

Also small peaks such as 7°C for 1 hour has very little impact on shelf life you may lose about 1 day.

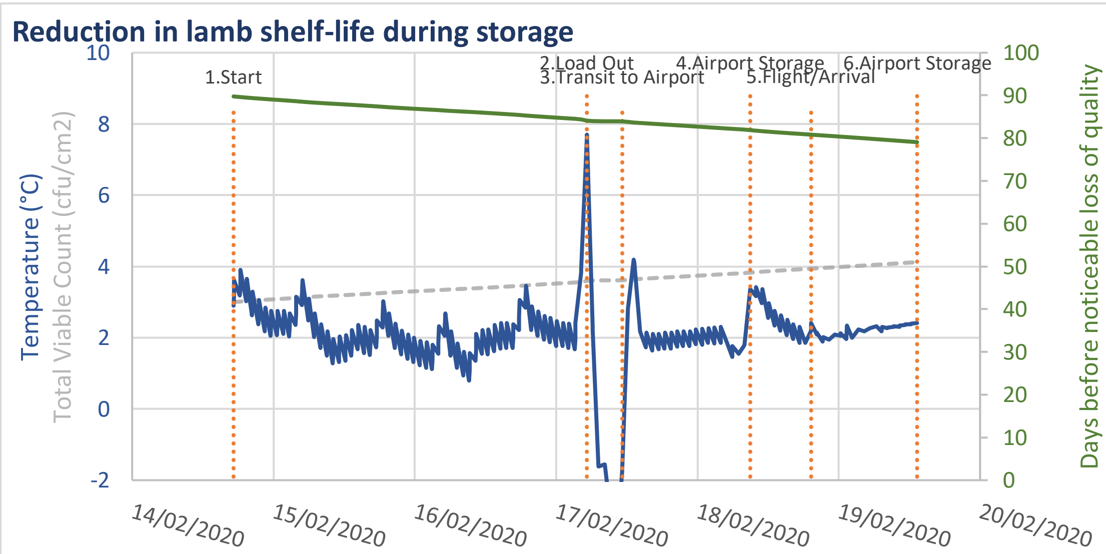
Temperature usually rises during loading or arriving at port

2.2. Air Shipments examples

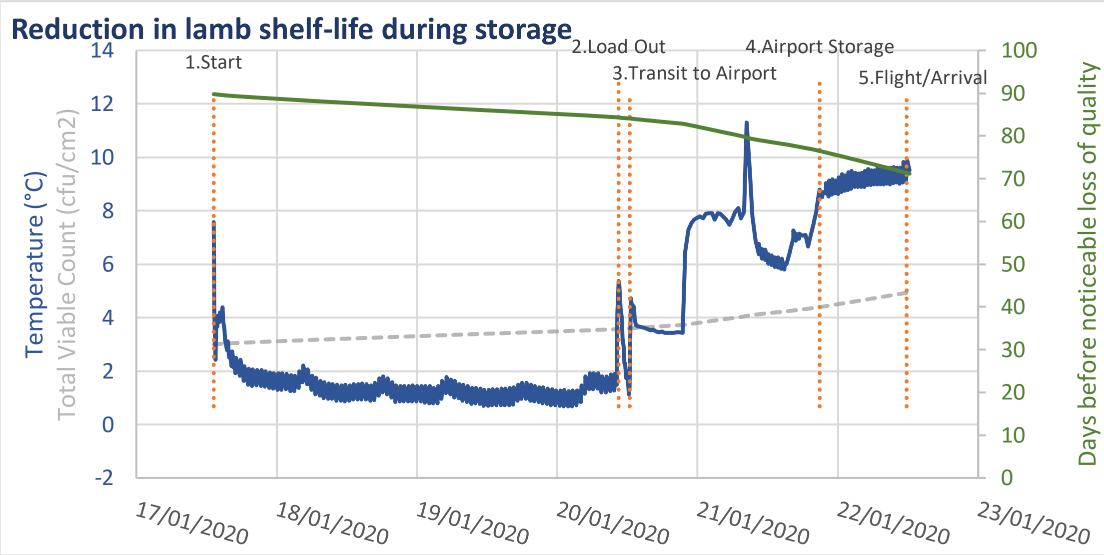
a) A UBS logger example



b) Asia – A good example



c) Dubai – Not so good example

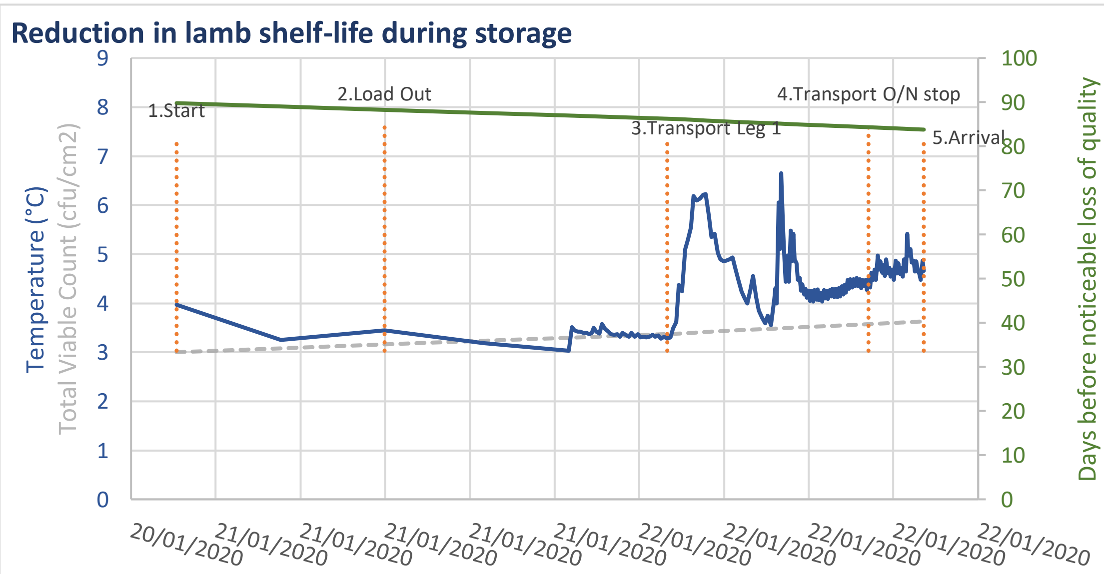


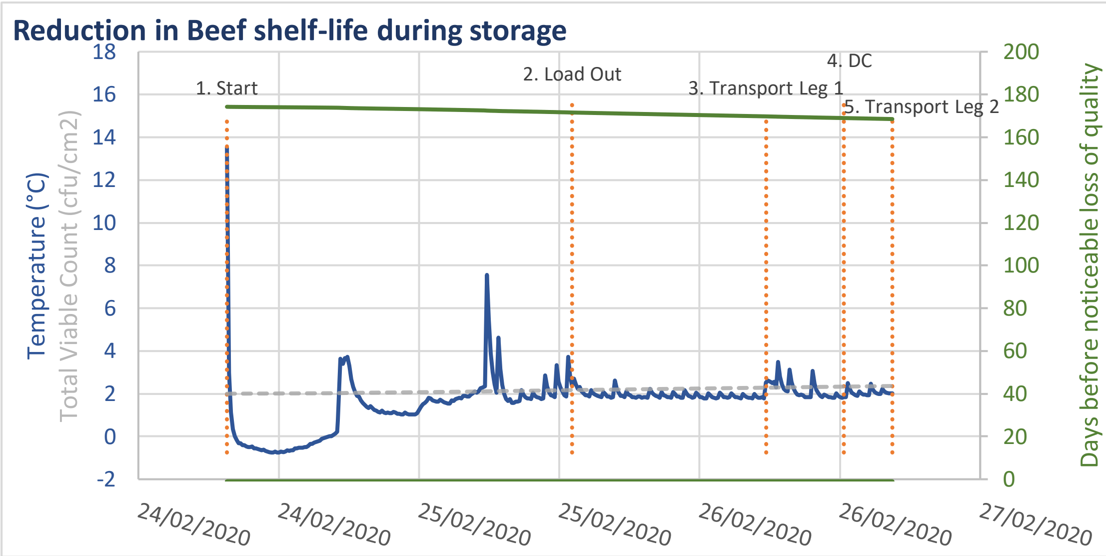
d) Common trends, impact on shelf life and pit falls

Issues can occur during air freight, and the mistake can be costly as they are usually High value products. However due to the overall transport time, the impact of the temperature spikes are not as catastrophic on the product.
To reduce the risk, it is best to ensure product arrives at the freight forwarder at a good temperature and dry ice is being used during transit. It should be noted that dry ice can only maintain product temperature.

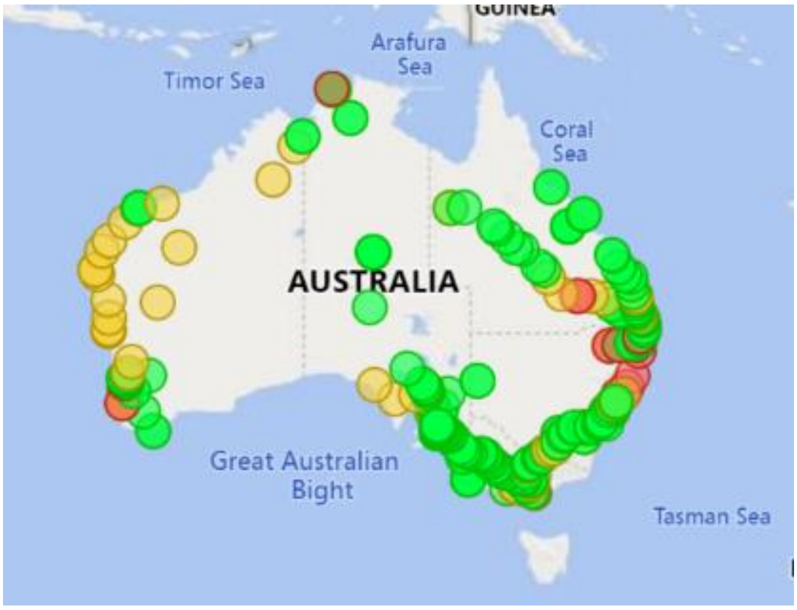
2.3. Domestic supply chain examples

a) Examples of cold domestic cold





Below are a 100 tracks of individual segments, due to the complexities of the domestic supply chain, each (abattoir to processor, processor to retail DC and processor to retail store) of the domestic supply chains and stitched together to provide a sample set represented of the whole Australian meat supply chains.



	Temperature threshold		
Supply Chain Legs	Green	Amber	Red
Abattoir & Processor (value adder)	-1 to 2 ^{0}C	2.1 to 5 ^{0}C	5.1 ^{0}C or higher
DC	2 to 5 ^{0}C	5.1 to 7 ^{0}C	7.1 ^{0}C or higher
Retail Store	3 to 7 ^{0}C	7.1 to 9 ^{0}C	9.1 ^{0}C or higher
Transport legs	2 to 5 ^{0}C	5.1 to 7 ^{0}C	7.1 ^{0}C or higher

b) Common trends, impact on shelf life and things to look for

As would be expected, journeys from retailer DC to stores in regional Australia were typically longer. The result also show that maintaining optimal temperatures on regional routes, and particularly in January (Australian Summer), is challenging.
If a processor delivers at optimum temperature to DCs, DC's are well placed to maintain temperature during the storage time.
If product is delivered above optimum temperature specifications, the product needs to be re-chilled which potentially adds refrigeration costs and dwell time, as well as the inherent loss of shelf life.

3. Additional recordable data from real time loggers

Depending on the brand of logger you use, some have additionally environmental measurements such as:
Location (GPS/Wi-Fi/Triangulation) – This gives a rough location data to pin point where the issues along the supply chain it has occurred. Some have GPS functionality, but this will significantly decrease your battery life where as Triangulation will be more efficient.

Light – indication when the carton has been opened. A good indicator to show when the product is either about to be used for further processing or by customers. Light measurements are in LUX and not a linear scale.

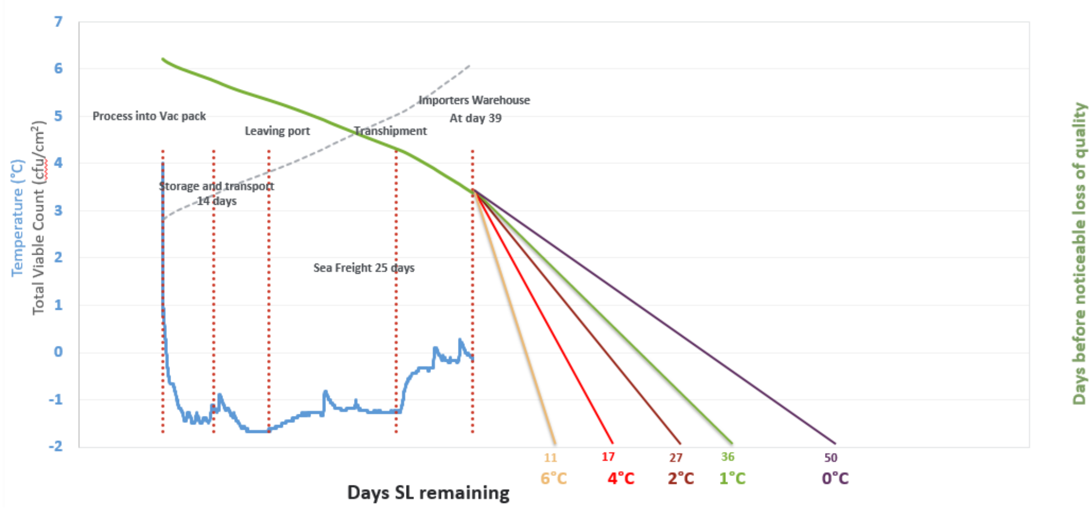
Motion/gyroscope – to detect if the box has been dropped during transit or what's it orientation during storage such as sideways or even upside down.

Relative Humidity – Allows to detect the performance of carton.

4. Methods of analysis and additional recorded data

a) Shelf life remaining on arrival

Understanding the cold chain as your customers receives the product gives further information that can be provided to the customer to illustrate the impact of each shipment. This can help customer to understand the significant of their cold chain and set realistic shelf life. As a rule of thumb, every 1$^{\circ C}$ increase will reduce the shelf life by 30%.
This becomes extremely important when your customer wants more shelf life or storing the product at sub optimal conditions, without understanding the temperature requirements. The graph below will show.



b) Average time of shipment to destination

Another method to use data is by determining the average time of shipment to destination, below are the average shipping time and temperature for sea-freighted chilled sheep and beef meat to Dubai. Shipping times and temperatures were identical for sheep and beef because beef time/temperature data were used to estimate the shelf-life of sheep meat. By using this data you can roughly estimate when the shipment would arrive and can give your customer the average shelf life remaining. More importantly, will your customer use the product before it reaches its shelf life end.

Figure 4.1: Distribution of shipping times (days) for product (sheep and beef) transported from Establishment to Dubai. Vertical bars show the number of trials in each data range. Data ranges are read from the previous ‘x’ value to the value under the bar. For example, the first bar on the left tells us that there was one shipment with a transport time of >26 but ≤30 days.

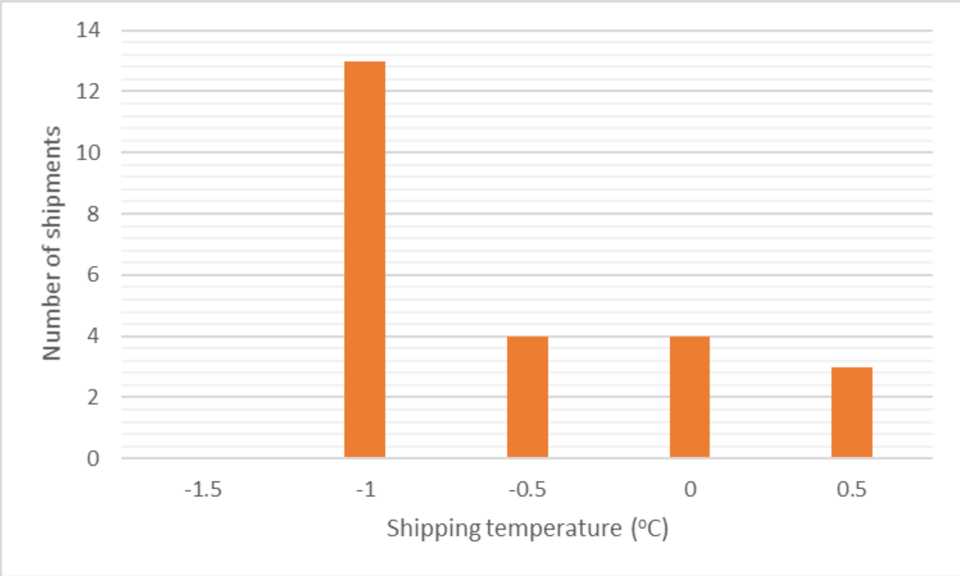


Figure 4.2: Distribution of average shipping temperatures (°C) for product (sheep and beef) transported from Establishment to Dubai. Vertical bars show the number of trials in each data range. Data ranges are read from the previous 'x' value to the value under the bar. For example, the first bar on the left tells us that there were 13 shipments with an average transport temperature of >-1.5 but ≤-1 °C.

The distribution of remaining shelf-life at -0.5°C for beef and sheep meat is shown in Figure 4..

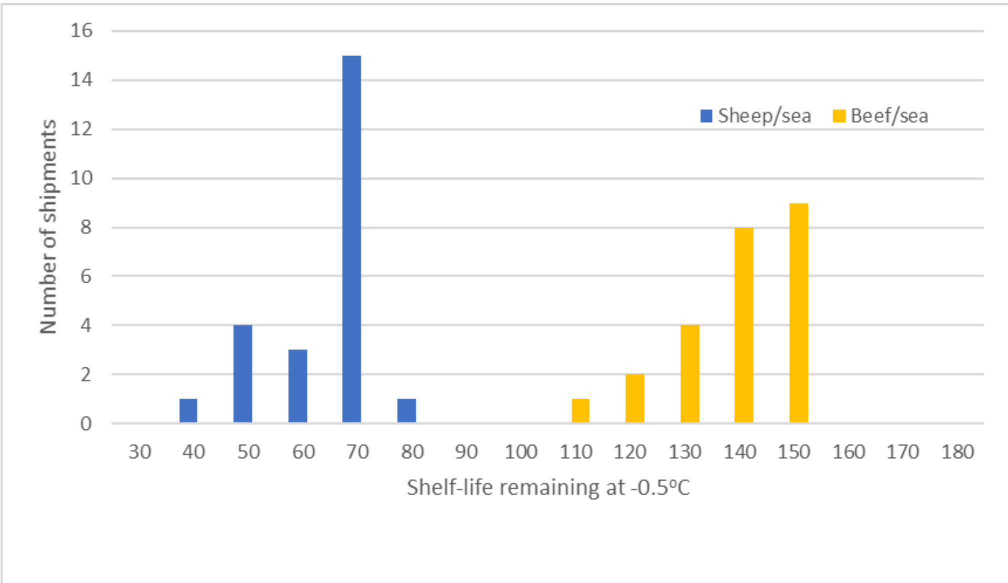


Figure 4.3: Distribution of shelf-life remaining (in days) for beef and sheep meat shipped from Establishment to Dubai, when stored in Dubai at -0.5°C. Vertical bars show the number of shipments in each data range. Data ranges are read from the previous 'x' value to the value under the bar. For example, the first bar on the left tells us that there was 1 shipment of sheep meat with >30 but ≤40 days shelf-life remaining at -0.5°C.

The values obtained from the model can also be used estimate the impact of proposed shelf-life criteria. A regulatory shelf-life of 120 days for beef and 90 days for sheep has been suggested for Australian product shipped to Gulf countries.

a) Sea fright vs Air fright

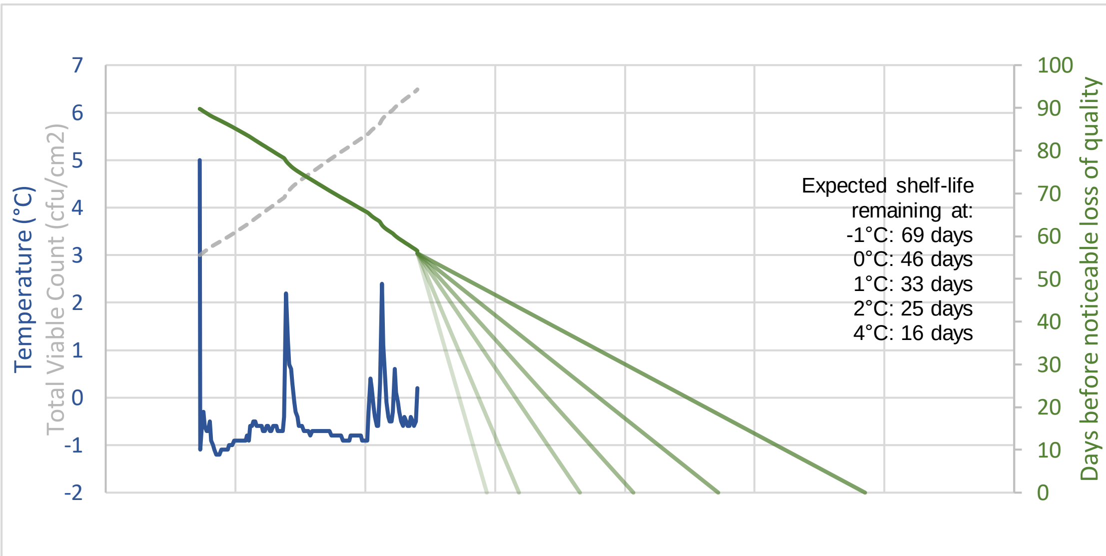
Sea fright is typically much cheaper (roughly one fifth) than air however with the disadvantage of taking longer to arrive, and the common perception of much less shelf life on arrival. Below is 1 example of sea freight to Dubai and 2 Air freight (one good one bad) in table and graph form for lamb primals.

As illustrated below, if the customer stores the product at roughly 2 - 4°C the different in shelf life is about 10 – 7 days difference, this may not be worth the increase in transport cost. More interestingly, if you look at the total shelf life the sea freighted product has more shelf life compared to air.

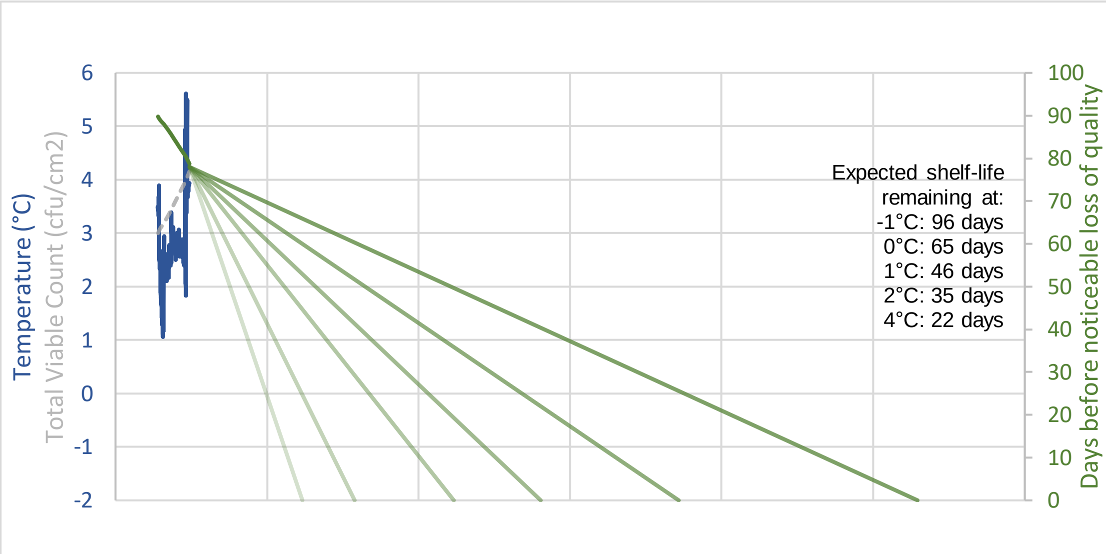
Table 4.1 – Shelf life remaining for lamb on arrival for sea vs air fright

	Total Shipment time	Shelf life remaining on arrival if stored at (°C)				Total shelf life based in 0°C
		0	1	2	4	
Sea - Typical	34	46	33	25	16	80
Air 1 - Typical	4	65	45	35	22	69
Air 2 - Good	4	70	50	38	23	74

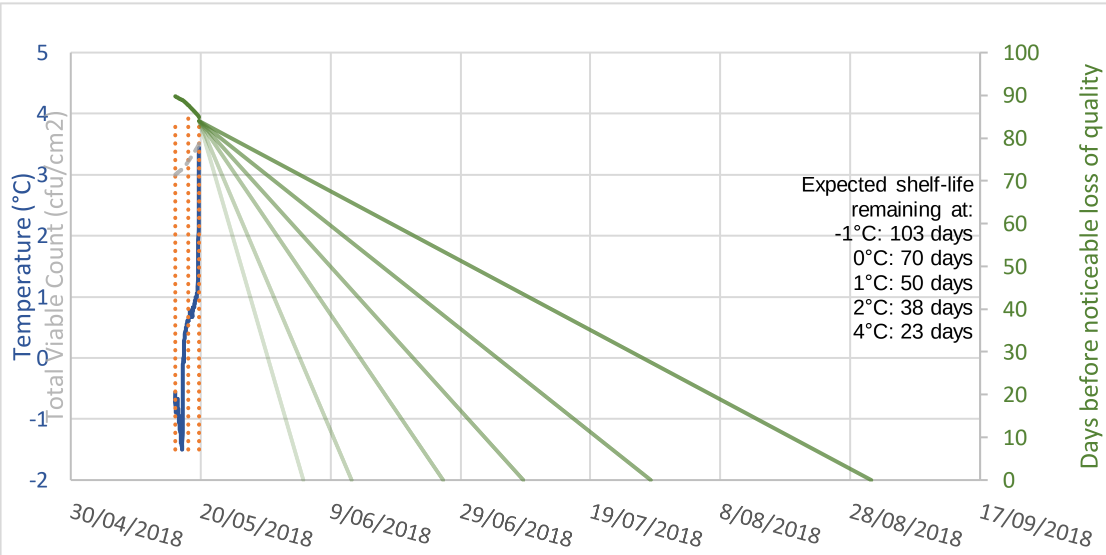
Sea freight – total 34 days transport – typical



Air freight 1 – total 4 days transport – typical



Air freight 2 – total 4 days transport – A very good example



b) Frequency distribution of the remaining labelled shelf-life

Frequency distribution need a minimum of 25 cold chain tracks of a single individual cold chain. It gives a very good statically calculation of the remaining shelf life relative to the label the graph below shows an example.

A "Frequency distribution" of remaining shelf-life is very useful to inform the potential of running into issues based on the label on the carton. By using the measured shipping times and the theoretical remaining shelf-life of product on storage it is possible to determine the impact of the labelled shelf-life.

The Solid **blue** line is the remaining labelled shelf-life of product when it landed, the Labelled shelf life is what you put on the carton labels. Which is usually 90 days on your product but it can take anywhere between 30-40days to reach the customer. So when your customer gets it, they will read the label as about 55 days left.
The Grey line shows product shelf life remaining if customer stores it at -1.5C. It shows most product has more than the labelled shelf life so that's good.
The green line is the remaining shelf-life predicted if product were held at -0.5°C. as you can see this is intersecting the Labelled shelf life. This is an important point.
The green shows 1/3 of the product will have shelf life GREATER, then what is on the carton label. So you are safe that the product will last the 90 days on the label. Black shows you are cutting it thin and getting it just right.
Red shows that you are running the risk of the product may have expiring before reaching what on the carton label and the Dotted lines are the predicted shelf-life remaining at holding temperatures greater than 0°C, and because it's on the left side of the labelled shelf life, its reaching the end of shelf life before what is on the label.

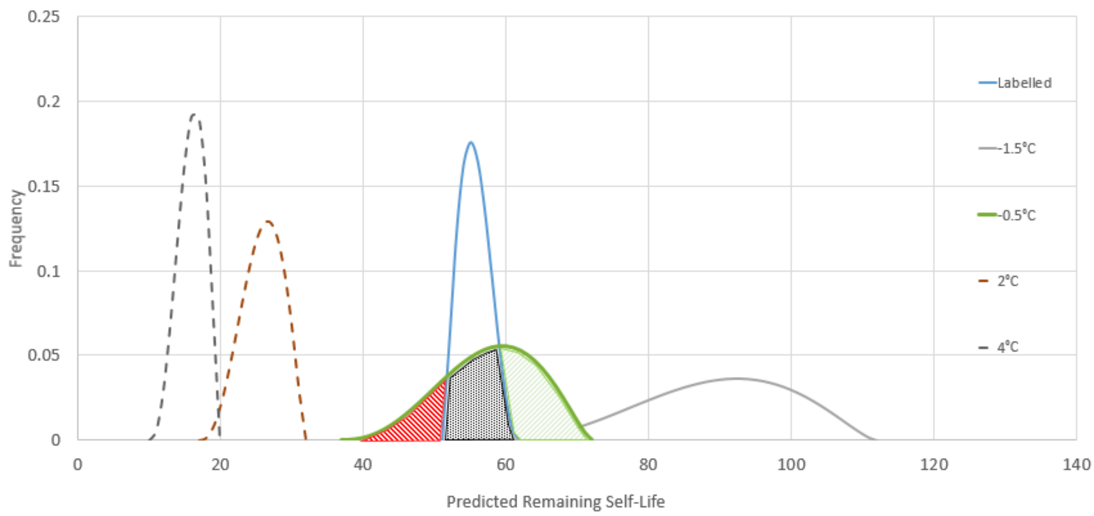


Figure 4.4: Frequency distribution of the remaining labelled shelf-life solid lines for sheep meat and the predicted remaining shelf-life at different temperatures. Product sea-freighted to Dubai.

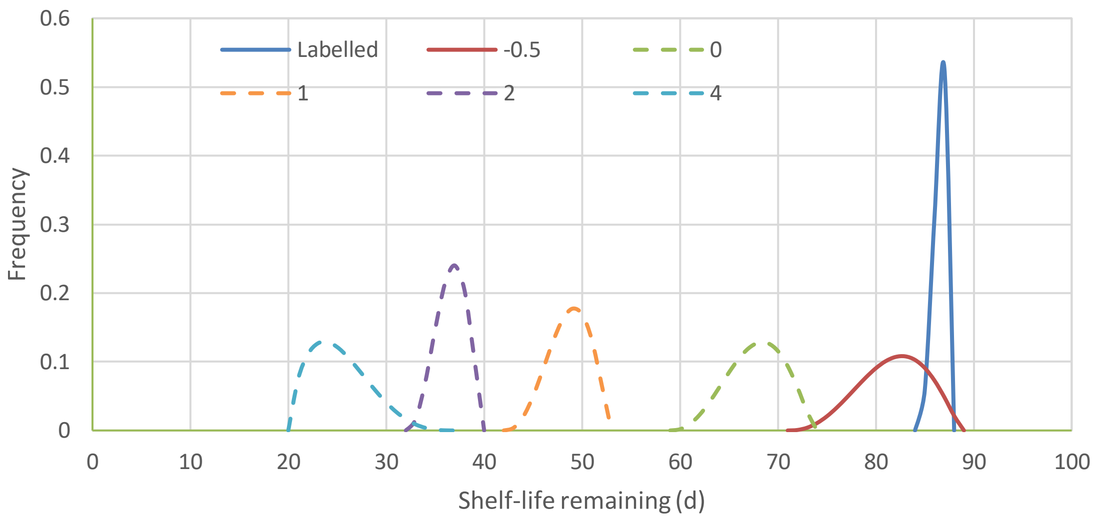


Figure 4.5: Frequency distribution of the remaining labelled shelf-life solid lines for sheep meat and the predicted remaining shelf-life at different temperatures. Product air-freighted to Dubai.

Below are steps on how we got the graph:

1. Find the labelled shelf-life, for this trial beef and sheep meat was set at 120 and 90 days respectively, by the importing country
2. Work out your Max, Min and average shipping time from the logs
3. The remaining theoretical shelf-life is calculated by subtracting the shipping time from the labelled shelf-life using the UTas model with the storage temperature set at -0.5$^{\circ C}$
4. You can add a range of different temperatures such as those closer to your customers storage conditions
5. The difference between the labelled shelf-life and the actual shelf-life remaining was visualised by converting the minimum, maximum and average values into approximate normal distributions (**Error! Reference source not found.**) with temperature ranges up to 4°C

a) Segment analysis 1 for ratio of days lost during shipment

This can help solve segment problems and focuses on gaps in the cold chain that has significant impact on the shelf life of product. However it also needs to be in context with the Time spent within that segment, for example a high temperature for 4 hours, could be a rate shelf life loss of 5 times (7°C) but it is only for 2 hours which is equivalent to 1 days lost relative to a rate of loss of 2 times (1°C) the rate for 30 days which is equivalent 60 days lost.

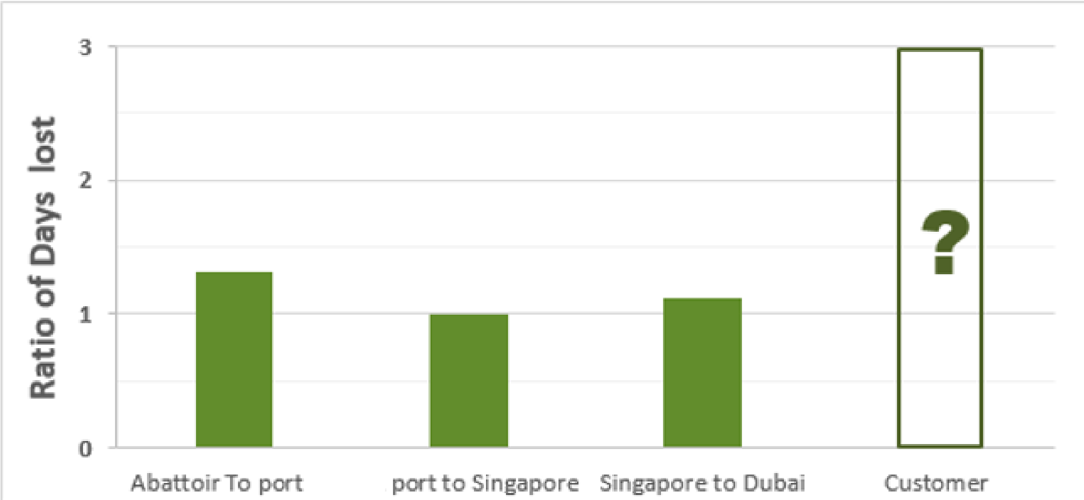


Figure 4.6: Segment analysis for ratio of days lost during shipment.

Figure 4.6 shows an example of a shipment with good temperature control through the supply chain, however some improvements could be made for product from abattoir to port. The limitation you'll face with USB loggers is that this analysis will only tell you to the point of logger collection, which is usually at port.

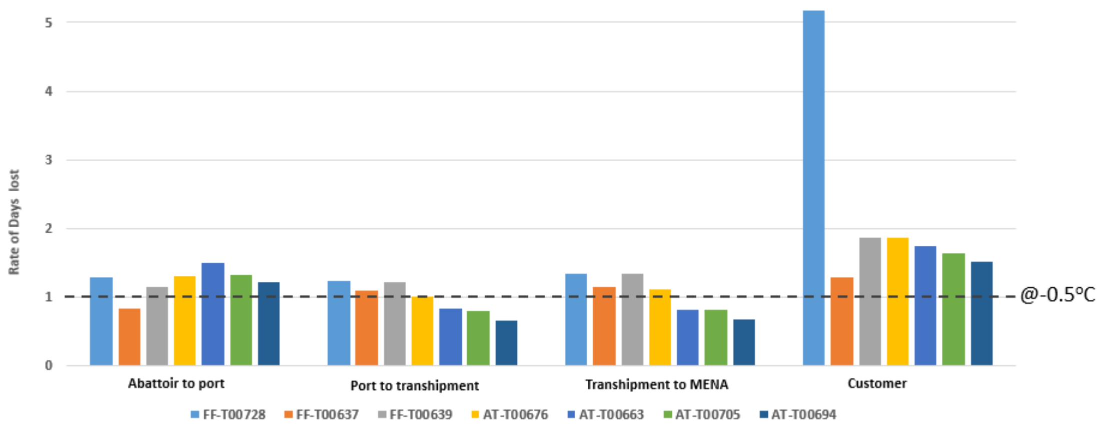


Figure 4.7: Segment analysis for ratio of days lost during shipment.

Using the data above you are able to break down the supply chain into segments and perform an analysis of where shelf life loss is the fastest/worst. The best way to illustrate the concept is by calculating the Ratio of Days Lost during each segment. Noting that for every day product is stored at -0.5°C, 1 day of shelf life is lost. At storage of 0°C the rate of lost is 1.2 and 2°C would be at the rate of 2.2 days per day.

b) Segment analysis 2 for days lost against days stored

Similar to Segment analysis 1, the graph below demonstrate the days lost relative to the Days stored, this can be very simple to visually show the amount of life lose during each part of the supply chain and

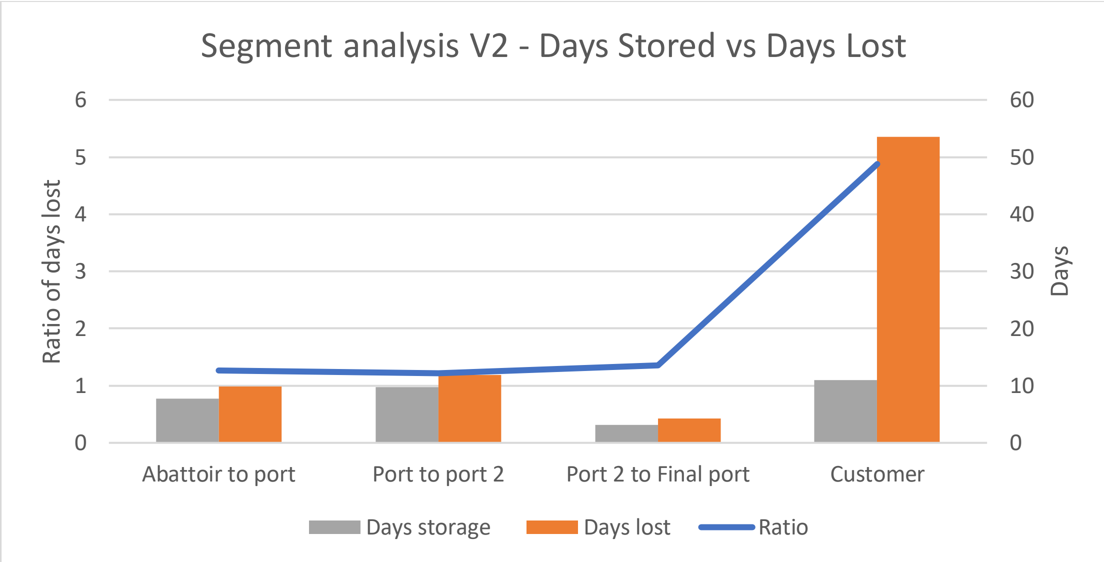
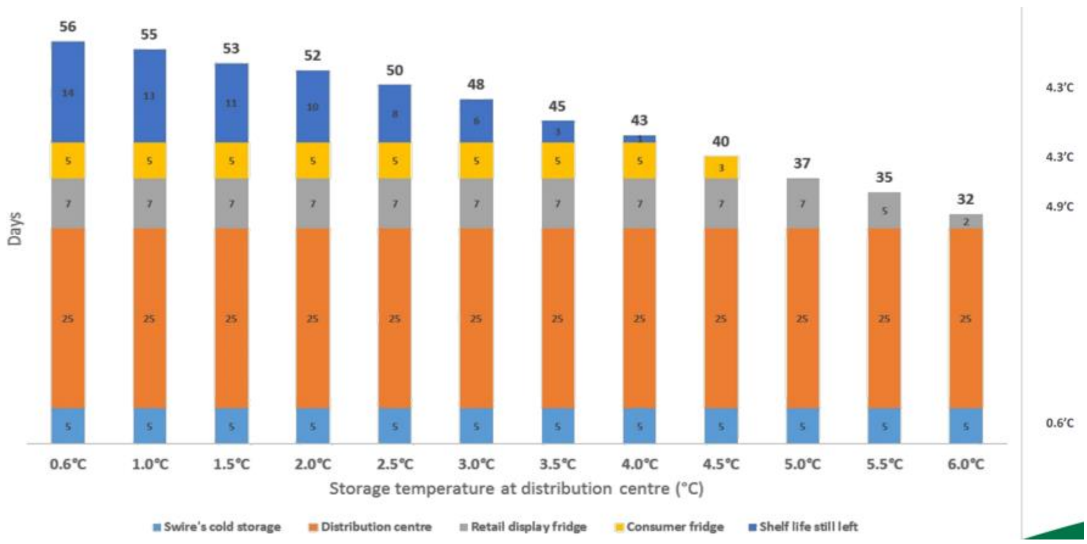
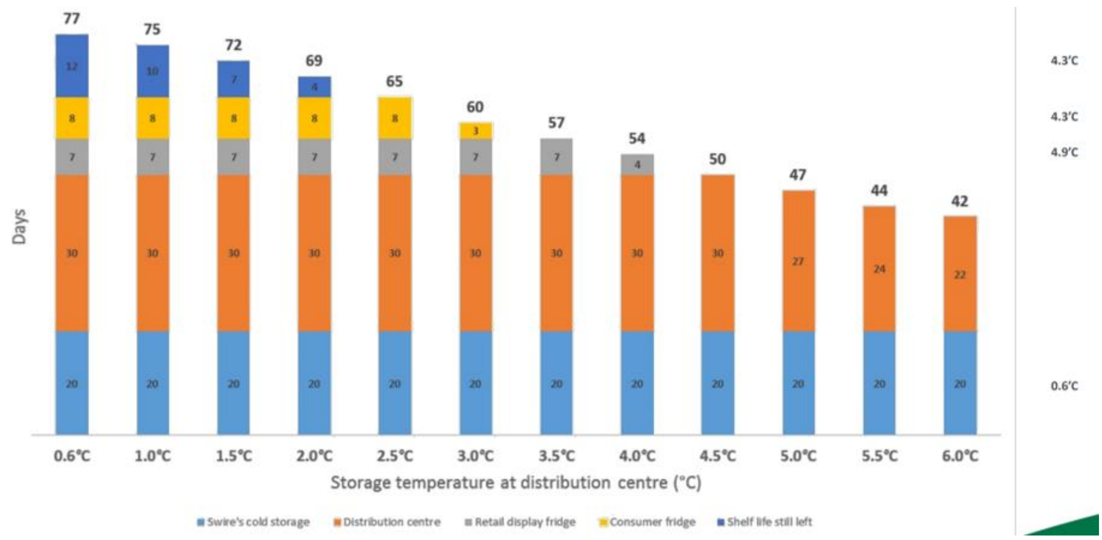


Figure 4.8: Segment analysis for days stored vs days lost during each segment

c) Temperature manipulation and storage time of the cold chain

Manipulating the storage time and temperature has a significant impact on the overall shelf life. Using the graph below if a product is held at DC for 25 days at 4’C and the other parts of the supply chain remaining the same it will have a total of 43 days, whereas if you simply change the storage at time from 5 to 20 days at the cold store at 0.6’C and then hold at DC for 30 days at 4’C then continue its journey, you’ll have a total of 54 days, which is 11 days more.





5. Management options, and benefits of tracking the cold chain

a) Loggers as a cold chain management tool:

- Verify the current cold chain meets the current requirements or preforms as you expect
- Can be used on a random basis to validate your cold chain if there are usually no issues
- If you are uncertain of the cold chains such as a new customer or route, the loggers can be used more regularly to track the chain before you are confident with the cold chain performance.
- Monitoring your chilling profile of product on plant, off site or during transit

All the information will allow you to better manage your current cold chian or work/inform the customer to resolve and understand where the cold chain can improve.

b) Benefits of tracking the chain

A container of high value product can be valued up to $250,000, and losing it due to unforeseen circumstances can be devastating for the processor and customer. For the value of roughly $70 logger, the cold chain can be monitored and alter the processors to intervene immediately when issues occur. Alternatively the logger can inform which point of the supply chain the cold chain has failed at what temperature and for how long, this information can be used in the shelf life model and predict the impact. Potentially only losing 3 days on a product with 160 days, saving you $250,000 and the headache of lodging an insurance claim and increasing your insurance premium. In addition information on the occurrence of cold chain failure and claims are variable and highly dependent on customer, and product value a report from AFCCC "A Study of waste in the cold food chain and opportunities for improvement" estimated waste caused by subpar cold chain conditions are about 25%, which is worth $160m in product value

Other benefits include:

- Loggers will keeps a record of each shipment, and can be referred back, if issues occurs later
- Deter claims made by customers
- Understanding the cold chain and its performance
- Assist customer to understand their own supply chain
- Reduce waste due to only a short time temperature spike
- Target Gaps and breakdown in the supply chain

6. How to start tracking your supply chain/cold chain

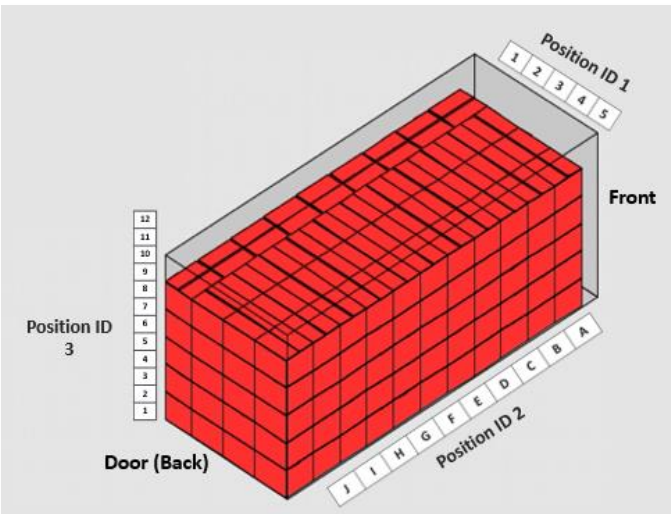
Here are some basic guide to start you on a journey to run the trial regardless of the type of logger you are using or the type of analysis.

a) Preparation:

- Order the loggers for the trial
- make sure all the loggers are set up accordingly to the manufacturer's instructions
- loggers that will go inside a carton could be placed in a sealable plastic bag if you wish to include a note letting the person who finds it know what the device is, what it is there for, and what they should do with it. Multiple languages may be necessary as to not surprise the receiver

b) On Plant:

- Place the loggers in the container, we recommend Placing the logger close to the back and high up to give it the best chance to get a signal during transport – but if you are using a USB logger it can be places anywhere in the container.
- The location can be defined using the Figure below (Template is in Appendix 1)



- Label cartons with stickers (figure below) to indicate which ones have loggers **(if you want the receiver to know there is a logger inside and retrieve the logger easier),** otherwise if you are using any real time loggers there is no need to retrieve them, so no need for big yellow stickers.

- Keep careful records about where the logger was placed, time it was started, the loggers unique ID and when it left the plant (this will give you a reference as sometimes the loggers may not be in your time zone).

c) During transit:

- Record the information from the shipping company about the dates/times of shipment's arrival and departure from each location on its journey
- If it's a real time logger, then you will be able to track data as it progress during the shipment as this will be more detailed than the shipping companies online tracking

d) Arrival in oversea markets:

- For USB loggers - Remove loggers and download/send loggers for analysis
- For Real time loggers, download the whole shipment from your login (consult your user manual)
- Analyse the data by using the shelf life model (Access can be granted from MLA) with the methods mentioned in section 4.

7. Appendix

7.1. Appendix 1 – Template for Data collection during trial

Logger Number	**Customer**	**Order number**	**Shipping Company**	**Container #**	**Production Date**	**Logger Position ID (Width) 1**	**Logger Position ID (Depth) 2**	**Logger Position ID (height) 3**

7.2. Appendix 2 – Summary of available loggers and its function*

	Reusability		Connectivity					Positioning system			Other environmental data			Cost and fees		
	Single	Reusable	Bluetooth	2G	3G	4G	5G	Cell	Wi-fi	GPS	Light	Relative Humidity	Shock	One off	Subscription	Data analysis
Tive T4000		X		X	X	X		X	X		X	X	X	X	X	Extra
Tive 5G	X	X			X	X	X	X	X	X	X	X	X	X	X	Extra
Tive (beacon)		X	X												X	Extra
Escavox		X			X	X		X							X	Included
Sensitech - TempTale GEO Eagle	X							X			X			X		Extra
Frigga logger	X	X			X	X		X			X		X	X		Extra
Roam Bee		X						X			X	X		X	X	Extra
Roam bee Beacon		X	X												X	Extra
Clever loggers		X	X									X		X		
Wireless loggers		X	X									X		X		

*The information provided was accurate at time of enquiry

7.3. Appendix 3 – Guidelines for developing a method for estimating shelf life of chilled raw vacuumed meat products

Scope

This appendix contain information designed to assist in the development of a protocol for undertaking shelf life estimation studies which will satisfy customer requirements.
The guide are based on information from publications and reports available in the literature and intended primarily for use with chilled, vacuum packed meat cuts, both ovine and bovine exported to distant markets.

Elements required in a shelf life protocol

Elements of a credible protocol include:

1. Design of a shelf life trial
2. Defining end of shelf life
3. Sensory testing
4. Microbiological testing
5. Chemical testing

Note that, where unique customer requirements are specified, they will need to be incorporated.

1. Defining end of shelf life

Shelf life ends when meat becomes unfit for use, human consumption, or sale; this may occur because of sensory reasons (appearance or smell) or microbiological reasons (a customer specification is exceeded).

2. Design of a shelf life trial

The aim of a shelf life trial is to estimate with reasonable accuracy the number of days that sensory and microbiological criteria of the meat product under test remain acceptable.
To do that meat samples need to be stored under conditions as close as possible to those to which they will be subjected in the marketplace, and samples withdrawn at key intervals to define the time when the product will meet customer requirements and expectations.
The shelf life trial should challenge the product until spoilage occurs, and this requires sufficient samples to allow testing to proceed past the expected shelf life of the product.

a. Sampling days

If the last day when the shelf life is still acceptable is defined as 100%, sampling may be focused around this expected day:

Sampling day	1	2	3	4	5	6
Shelf life used	0%	90%	95%	100%	105%	110%

If a customer requests more frequent sampling intervals these will need to be added to the above.

b. Number of samples

Shelf life trials are a cost of doing business and can be expensive particularly when high-value cuts such as striploins, cube rolls or rumps are used; laboratory and sensory testing also have their costs.

Key considerations are that:

- There are sufficient samples to go to the end of shelf life and beyond.
- Replicate samples at each sampling day – if only one sample is used and the pack turns out to be a leaker no result will be possible for this sampling day.

Three replicate samples is a good number and was used in trials on chilled meat in Australia (Holdhus Small *et al*. 2012; Kiermeier *et al*. 2013) and in Canada (Youssef *et al*. 2014).

If you're setting the shelf life for a vacuum packed (VP) beef primal your historical data may indicate around 160 days in your holding chiller.

In the trial below a total of 18 packs are used and samples are withdrawn at times around the expected shelf life and beyond.

Sampling day	1	2	3	4	5	6
Shelf life used	0%	90%	95%	100%	105%	110%
Days after storage	0	144	152	160	168	176

If we trial the shelf life of VP lamb primals, again we use a total of 18 packs and we focus on the time around the expected shelf life (around 90 days) and beyond.

Sampling day	1	2	3	4	5	6
Shelf life used	0%	90%	95%	100%	105%	110%
Days after storage	0	80	85	90	95	100

Note that the above are suggested sampling times - actual schedules should be based on historical product knowledge and also on customer requirements.

It is also wise to include 2-3 'spares' in case you find a 'leaker' pack among the stored samples.

c. Type of cut and packaging

Ideally you use cuts taken from the boning room immediately before they are packed into their cartons as was done in the study by Holhus-Small *et al*. (2012) where strip loins and cube rolls from six abattoir in Australia were tested.

To minimise expense cuts are sometimes divided before packaging e.g. Canadian researchers divided strip loins into two before packaging (Youssef *et al*. 2014). For this particular cut the procedure probably has no influence on the shelf life since the bag has the appropriate dimensions for the cut and sealing can be done without any impact on the heat seal and there should be no creases to trap air.

It is tempting to divide a primal cut into as many small pieces as possible e.g. cutting a strip loin into 10-12 steaks. This should be avoided because the surface area:volume ratio of the steak is very different from that of an entire strip loin and the shelf life of a steak may not represent the shelf life of an entire cut.

d. Storage temperature

The choice of storage temperature depends on customer requirements or the storage temperature recommended to the customer by the establishment.

For a domestic retailer a good temperature is 5°C since that will be their retail display temperature; the retailer may also require shelf life to be established at 8°C – this is termed an "abusive temperature".

For an overseas customer a good temperature is close to 0°C since this approximates what is achieved in a refrigerated container.

Since temperature has such a large influence on shelf life at least one data logger should be included in your trial, located securely between two individual cuts and maintained *in situ* for the entire trial. The data file from the logger should be kept with other documentation from the trial

3. Sensory testing

a. Training a sensory panel

When meat is assessed senses are used: eyes, nose and mouth and, unlike machines or instruments, individuals don't all assess the same product in a uniform manner.

For this reason it's necessary to assemble a sensory panel/team; the number panellists can vary but three is the minimum number required.

Panels are more effective if each individual receives some training on how to interpret what they are seeing, smelling or tasting. This can be achieved by exposing panellists to products with a range of attributes so they become experienced in what each descriptor means e.g. "Moderate odour" (see section 3.5 for more detail).

The panel will also need training in how to fill in the assessment sheets and on the golden rule of doing the assessment without communicating their thoughts to any other panellists, at least in the first instance.

If sample packs are sent for evaluation to an off-site laboratory it is necessary to establish the necessary skills are in place and that an acceptable protocol will be followed.

b. Creating a suitable area for assessment

Product should be assessed in an area which is quiet, well-lit and not cramped.

A laboratory is a good location as benches can be cleaned after the panel has finished, and any spilled liquids removed.

c. Assessing appearance of the pack

When a carton is opened the first criterion to note is whether a pack has leaked, in which case there will be a putrid odour.

The leaker must be discarded from your test and removed from the testing area.

It's prudent to remove other packs from the carton and wipe them clean with a damp paper towel, and to remove the plastic liner and replace it before putting packs back in the carton.

The next criterion to note is the amount of drip/purge/weep.

A 'normal' amount of drip is 1-2% of the weight of the cut, with seam-boned primals losing less than pieces subjected to trimming/cutting e.g. denuded knuckle (CSIRO, 2002).

Drip may also increase if individual cuts have been packed into the carton so that those at the bottom are under pressure.
In commerce, excessive drip is not equated with end of shelf life, though it may become a compensation claim.

d. Bag integrity

Before opening the pack the seams should be examined to check whether there is any 'doubling-up' caused by the bag not being laid correctly on the heat seal bar.
Assess also whether there are folds in the bag. Air becomes trapped if the bag doesn't fit closely over the meat and allow aerobic growth; folds also facilitate production of drip.

e. Opening the pack

The pack is opened by slitting just beneath and along the line of the seam.
There is almost always an odour detectable on opening the pack, usually slightly sour, which dissipates after a few minutes. It is called confinement odour, is a normal occurrence as the meat ages and should not be considered as part of the odour assessment.
The odour which must be assessed is that which persists around the meat when it has been removed from its packaging for a few minutes.

f. Assessing odour

Training will involve exposing your team/panel to various odours, which involves guiding them to assessing terms such as sour, acidic, cheesy, sweet, sickly, putrid and to other descriptors such as slight, moderate and extreme.
Experienced team members with good industry and product experience are best suited to perform product sensory assessments; sales staff can be especially useful because they deal with customers and their perceptions
The essential feature of odour assessment is that each panellist is "grounded" in identifying unacceptable odours and this may take continuous coaching/guidance from the leader of the sensory team.

g. Meat colour and bloom

When meat is removed from the vacuum pack it should quickly regain its bright, red colour (bloom).

h. Scoring the assessments

Panellists score their observations against a set of criteria for which they have received training on a score sheet.

All score sheets have a scale in which criteria gradually change from acceptable to unacceptable.
The number of points on the scale can vary from 9-point to 4-point.

Sensory score sheet with 9-point scale

Attribute

Vacuum	Appearance	Odour
8 = complete, tight package adhesion **6 = good vacuum** **4 = moderate vacuum** **2 = poor vacuum** **0 = no vacuum, probable leaker**	**8 = very fresh, no discolouration** **6 = fresh, slight discolouration** **4 = good, acceptable** **2 = poor** **0 = severe discolouration**	**8 = fresh, no off odour** **6 = slight off odour** **4 = medium odour** **2 = strong off odour** **0 = extreme off odour**

The point when shelf life expires on the 9-point scale, above, is the time when either the appearance or odour reaches a score of 2.

Note that a score of 2 for vacuum leads to a consideration of whether the pack is a leaker before rating that the shelf life has expired; only intact packs should be used for shelf life assessments.

Sensory score sheet with 5-point scale

Score	Drip	Vacuum	Appearance	Odour
4	None	Complete adhesion	Deep red colour	Fresh
3	Slight	Good	Light red colour	Slight sour/dairy
2	Acceptable	Moderate	Slight discolouration	Sour/dairy
1	Heavy	Poor	Poor colour	Strong sour/dairy
0	Extreme	None/blown	Severe discolouration	Off odours

The point when shelf life expires on the 5-point scale, above, is the time when either the vacuum, appearance or odour reaches a score of 1; note the remarks above re whether the pack is a leaker.

Similar criteria are covered in a 4-point sensory scale, where the cut-off point for acceptability is a score of 1 for either colour or odour.

Sensory score sheet with 4-point scale

Score	Vacuum	Colour	Odour
3	Seal intact, minimal drip	Purple/red	Fresh
2	Seal intact, normal drip	Purple/red	Slight stale
1	Broken seal, slack pack, excess drip	Two toning, browning	Strong stale/dairy
0	Broken seal, copious drip	Brown, grey colour	Putrid

i. Reaching a consensus

When the panel has completed its assessment the scores are compared and evaluated.

There will be occasions when discrepancies occur e.g. sometimes a panellist scores differently from other team members and the discrepancy will need to be resolved by re-training the panel.

On occasion, all panellists may agree that one of the three packs sampled is unacceptable and two are acceptable. In this case it is advisable to open three more packs to assist the decision on whether end of shelf life has been reached.

When the panel determines that all three packs are unacceptable terminate the end of shelf life has been reached. A safe shelf life is therefore the previous sampling day when all three packs were acceptable.

4. Microbiological testing

While some customers impose only sensory specifications or proportion of shelf life remaining when the consignment is accepted, others set a microbiological criterion and we describe some criteria set by importing countries and Australian supermarkets in Chapter 9 of MLA's *Shelf life of Australian Red Meat*.

a. Sampling meat for microbiological testing

Methods for removing bacteria from meat surfaces fall into two categories:

- Destructive sampling, where tissue is removed
- Non-destructive sampling, where the meat surface is swabbed, sponged or palpated to remove bacteria into a surrounding medium (so-called 'meat-in-bag' technique).

Destructive sampling

It is generally agreed that excising surface tissue, then blending or stomaching it, will result in greater recovery of bacteria than will non-destructive sampling methods (Capita *et al*. 2004). For those establishments which have laboratory staff skilled in excising tissue and blending it using aseptic technique, excision sampling is considered the 'gold standard'.

Non-destructive sampling

The numbers removed by non-destructive sampling vary widely according to the vigour with which the tissue is rubbed and to the abrasiveness of the sponge or swab.

Gill and Jones (2000) found that recovery was lower when cotton wool swabs were used, compared with excision samples and with samples obtained using a sponge or abrasive gauze pads, with the difference in TVC/cm^2 when chilled carcases where sampled was around 0.5 log.

In Australia, Seager *et al*. (2010) monitored the recovery of bacteria from beef carcases using ten experienced samplers. On average, about 40% of the total bacteria on the meat surface was removed by using a Whirlpak sponge but the standard deviation at each site was high, reflecting the wide variation of recovery among operators (2.3 - 93.1%).

Using a Whirlpak sponge for shelf life testing may be a favoured method given that all establishments use this technique for ESAM testing.

An alternative non-destructive method was used by Holdhus Small *et al*. (2012) in which rinse samples were collected from the primal by placing it in a sterile bag with 500mL of sterile saline and massaging its surfaces for 2 minutes.

This technique is widely used in the poultry industry and has the advantage that bacteria are removed from all surfaces of the meat, and the disadvantage that converting the count on the plate to a count/cm^2 requires a mathematical formula (Holdhus Small *et al*. 2012 show how to do this for strip loins and cube rolls).

b. Media used in estimating microbial counts

In research studies such as those quoted previously (Holdhus Small *et al*. 2012; Kiermeier *et al*. 2013; Youssef *et al*. 2014) a range of culture media are used to enumerate bacteria which dominate the population during the various stages of shelf life. Information on these bacteria is presented in Chapters 5, 6 and 7 of MLA's *Shelf life of Australian Red Meat*.

In general, for the purpose of gathering microbiological information to accompany an Aerobic Plate Count (APC) is sufficient. Of course, if customers specify a suite of organisms their requirements must be met.

c. Incubation temperatures

Because shelf life is assessed by storing meat under refrigeration for many weeks the dominant microflora is composed of psychrotrophic bacteria.

Psychrotrophs generally have a temperature optimum of 15-25°C and a maximum growth temperature of 30-35°C (ICMSF, 1980) and it is logical to incubate cultures near their optimum (25°C) for sufficient time (4 days) so the colonies are clearly visible and therefore countable on the culture plate.

This was captured by an Australian Standard *(AS 1766.3.1-1991) Food microbiology Method 3.1: Examination of specific products - Meat and meat products other than poultry: Standard plate count. Incubate at 25 ±1°C for 96 ±2 h. Examine the plates after 72 ± 2 h, and record the counts for those plates that are likely to be overgrown before the full incubation period has elapsed.*

While this Standard has been replaced by less prescriptive standards it is recommended that cultures are incubated for 4 days at 25°C.

The importance of using the correct incubation temperature in monitoring shelf life studies is captured by Pothakos *et al*. (2012) who incubated plate counts of stored food samples at either 22°C/5 days or 30°C/3 days and found that counts from the former temperature were 0.5 – 3 log cfu/g higher. The authors concluded: *"This study highlights the potential fallacy of the total aerobic mesophilic count as a reference shelf life parameter for chilled food products as it can often underestimate the contamination levels at the end of the shelf life."*

d. Interpreting micro counts in shelf life studies

Early work by CSIRO during the 1980s showed that APCs reach very high levels – between log 7 and log 8/cm^2 (10,000,000 – 100,000,000/cm^2) when VP beef is stored around 0°C (Egan, 1983).

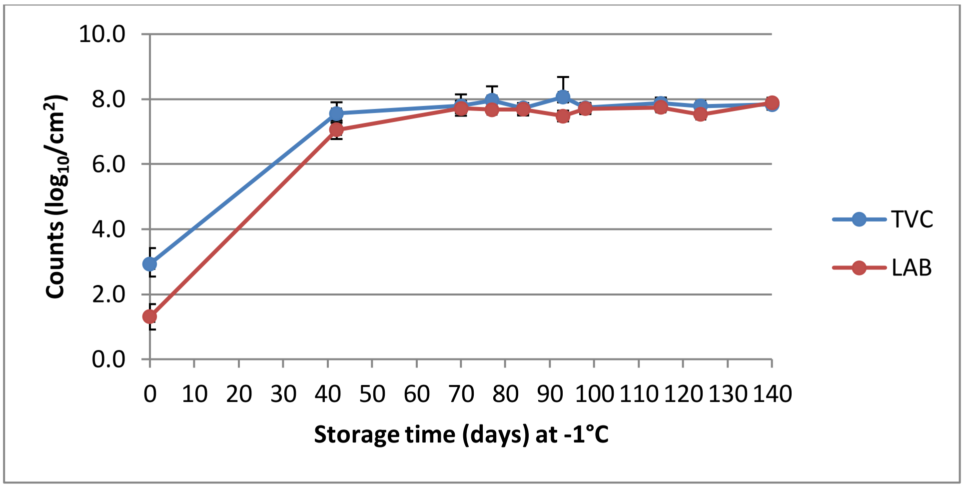
The meat is still acceptable when counts reach a maximum; only after several more weeks of storage do spoilage criteria become apparent.

The figure below is important because it shows that:

- A very high count is 'normal' in VP meat storage
- The dominant bacteria are lactic acid bacteria (LAB)

High counts towards the end of storage should not be of concern and customers should be reassured that such counts are not only normal but are the reason why vacuum packed primals have such long chilled storage lives.

Growth of total viable counts (TVC) and lactic acid bacteria (LAB) on vacuum-packed lamb meat stored at -1°C



5. Chemical testing

Chemical tests are not usually necessary as part of shelf life testing in the commercial setting, though knowing the initial pH may prove valuable.

6. References

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