AUSTRALIAN MEAT PROCESSOR CORPORATION

The impact of transport to Australia's distant markets on the shelf-life of beef and sheep primals

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Prepared by:	John Sumner
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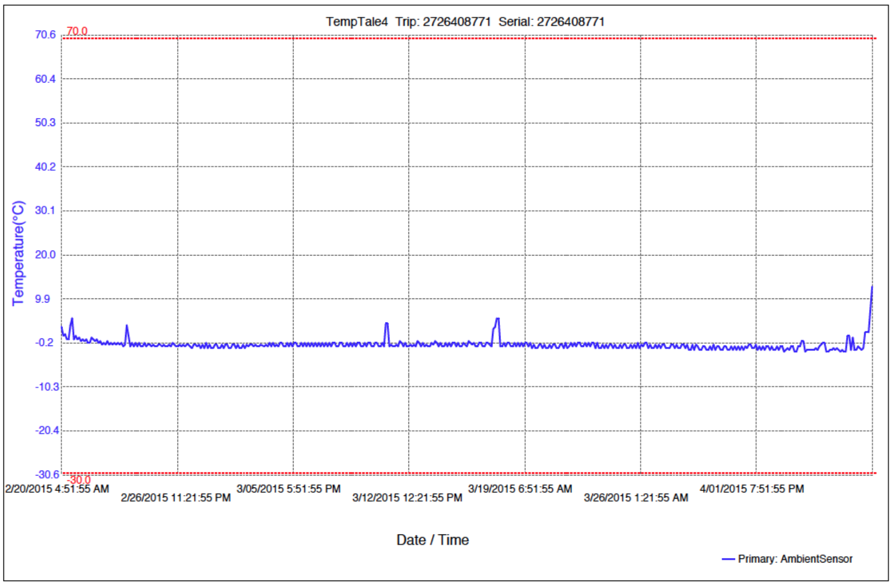
2.0 Executive Summary

A study has been undertaken on how the shelf life of vacuum packed beef and lamb primals from Australia to distant markets is influenced by conditions during shipping with Terms of Reference (ToRs) to:

1. Provide information on shipping times to each major market
2. Evaluate temperature:time relationships during shipping to each market
3. Assess the effect of temperature:time on the microbiological profile and shelf-life during shipping

To satisfy the ToRs, temperature:time records of meat in containers and has been entered into a software tool developed by the University of Tasmania (UTas) for predicting shelf life of vacuum packed (VP) chilled primals.

Understanding the temperature record of the voyage can be enhanced significantly if it is accompanied by tracking information to align with temperature "blips" when power to the container is removed during loading and unloading at various ports.



Australian meat establishment are served by shipping lines, which provide regular schedules to major markets, though intermediate trans-shipping is sometimes required.

Failure to meet the intended vessel can delay trans-shipping by up to one week (as shown mid-way through the voyage illustrated above between Melbourne and Southampton).

A number of Australian establishments market vacuum packed primals (usually lamb) to Middle Eastern and European countries by airfreight. Product handling at Middle Eastern airports can submit consignments to tarmac temperatures around 50°C, mitigated by use of dry ice and portable refrigeration units ("cold dollies").

In general, temperatures during forty-eight airfreight consignments to the Middle East and Europe were satisfactory, though on occasional consignments mean temperatures were "warm" (6.2°C) or "cold" (-

4.7°C) – both due to inappropriate addition of dry ice to the airfreight container. Because the trip length is generally short, airfreight to Europe allows ample shelf life for the purchaser to market through the retail chain (for which an arbitrary mean temperature of 4°C is used).

Table S1: Summary temperature statistics for airfreight containers monitored in this study

	Mean temperature for voyage (°C)
Mean	0.6
Standard error +/-	1.9
Minimum	-4.7
Maximum	6.2

Similarly, temperatures for 125 sea voyages studied generally kept product close to 0°C for the entire voyage with occasional departures up to 1.9°C. At this temperature, on long voyages e.g. to European ports, shelf life at 4°C remaining for the purchaser is only eight days for beef primals, while that of lamb primals will have been exhausted.

Table S2: Summary temperature statistics for sea containers monitored in this study

	Mean temperature for voyage (°C)
Mean	-0.17
Standard error +/-	0.7
Minimum	-1.8
Maximum	1.9

With one exception, sea transport to all major markets was found to proceed in a timely manner and at a satisfactory temperature. However, a number of voyages to west coast USA were disrupted by industrial action between members of the International Longshoremen and Warehouse Union and waterfront employers. The effect of the dispute was that total voyage length (from establishment cold store to clearing) was around 10 days longer, compared with "normal" docking and clearing.

Similar delays in trans-shipment in SE Asia up to nine days were found to have a significant effect on consignments to Middle Eastern countries in terms of complying with regulatory requirements surrounding shelf life.

Some importing countries impose requirements for shelf life of vacuum-packed meat such as:

- Available shelf life of 70 days from date of slaughter at -0.5 to 0°C
- Microbiological criteria for Aerobic Plate Count n=5, c=3, m=106 and M=107

Voyages described in this study indicate that a combination of delayed trans-shipping in Singapore or Malaysia, plus "warm" storage (mean 1.9°C) compromises compliance with such requirements.

Export of chilled beef to China offers Australian exporters specific opportunities for various lower-value cuts such as rib fillets and briskets, against which are challenges such as refrigeration infrastructure and capacity.

Based on the data gathered for consignments from one Australian establishment to a single Chinese importer the cold chain was maintained in the latter's cold store, with a mean temperature of -0.8°C until release of product from the importer. This resulted in generally low bacterial levels in product being delivered to customers (mean log 4.5 cfu/cm2) being predicted.

However, as can be seen from Table S3, shelf life at temperatures considered abusive in many countries (>4°C), is short and may not meet the expectations of some importers.

Table S3: The influence of in-country storage temperatures on shelf life remaining for utilisation

	Mean	Shortest*/Lowest**	Longest*/Highest**
Shelf life remaining at 2°C (d)*	51	39	59
Shelf life remaining at 4°C (d)*	30	23	35
Shelf life remaining at 6°C (d)*	19	15	23
Shelf life remaining at 8°C (d)*	14	10	16

The present study has identified a number of elements associated with international trade from Australia to distant markets which influence shelf life remaining to the purchaser:

(i) Starting bacterial level at vacuum packing.

A consignment will typically contain meat with a range of bacterial count at time of packing. While meat with the mean bacterial count will generally arrive at its destination with an acceptable final count around log 6 (1,000,000) cfu/cm2, meat at the 90th percentile may exceed log 8 cfu/cm2, with commensurate reduction in shelf life available to the purchaser.

(ii) Temperature and time product is stored before loading aboard the vessel.

Typically, an establishment books space aboard the container vessel and, when the container is released, it is filled promptly to align with the Estimated Time of Departure (ETD) of the vessel. On occasion, however, processing problems or disruption to the vessel's schedule delays loading of the container, which has a direct effect on shelf life.

(iii) Power-off during breakdown aboard the vessel, or at loading/unloading

Containers are taken off power during loading and unloading at dockside resulting in a rise in temperature depending on the time off power and the ambient temperature. Normally, the temperature rise is small and for a limited period, with a trivial impact on shelf life.

Examples were obtained where containers were off power due to a breakdown aboard the vessel. In one case, the temperature rose to 20°C over a 2-3 days period with the shelf life remaining for the purchaser being reduced from a predicted 23 days at 4°C to 16 days, if the breakdown had not occurred.

(iv) Slow steaming

High oil prices around 2009 resulted in major shipping lines reducing the average speed of container vessels from 20 knots to 17 knots/hour or slower in some cases, so-called “slow steaming”. The impact of slow steaming from New Zealand to Europe has been cited as extending the voyage by about one week to 53-56 days (Mills et al. 2014). By contrast, the present study established actual voyage times around 37 days from Australia to Europe.

(v) Journeys extended by disputes or extended trans-shipment times

The effect of industrial disputation has already been illustrated in Section 3.3.5, where, in a dispute on the West coast of the USA, total voyage length (from establishment cold store to clearing) was around 10 days longer during the dispute, compared with “normal” clearing.

(vi) Container set point delivers “warm” temperature over whole voyage

“Warm” container temperatures during long voyages have a marked effect on shelf life remaining for the purchaser. The effect is most marked with VP lamb primals, with average temperatures which may seem acceptable to the industry (<2°C) nonetheless compromising available shelf life in a retail cold chain at an average of 4°C (Table S4).

Table S4: Examples of “warm” container temperatures and effect on shelf life available to the customer at 4°C

Product/Destination	Lamb/Europe	Lamb/Middle East	Beef/USA
Voyage length (d)	48	31	47
Average temperature on voyage (°C)	1.9	1.9	1.2
Final bacterial level (log cfu/cm2)	8	8	8
Shelf life remaining at 4°C (d)	0	6	2

(vii) Macro temperature abuse during airfreight – “warm” and “cold” abuse

Human error sometimes results in a container not being connected properly to power, with ensuing lack of refrigeration, such as illustrated in Fig S1 where product was not refrigerated between Australia and Singapore.

The effect of the temperature abuse early in the voyage was that shelf life was exhausted about 10 days after loading aboard the vessel and that the entire consignment was spoiled.

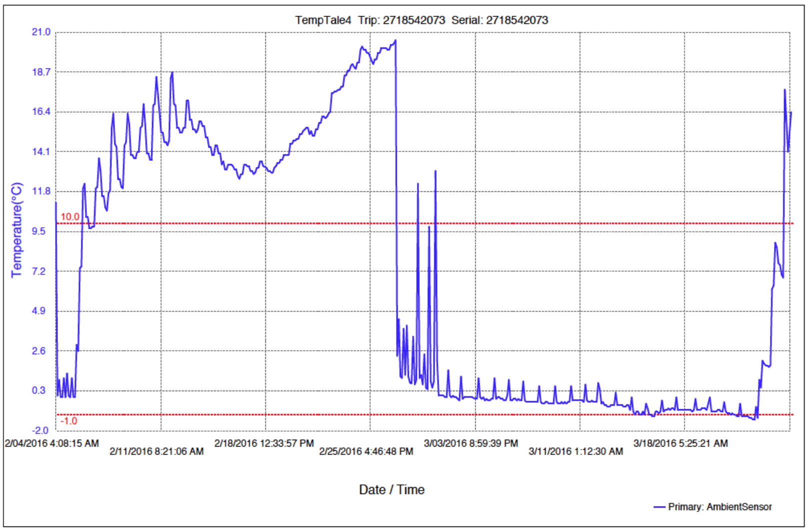


Fig S1: Temperature profile of a container not connected to refrigeration between Australia and Singapore

It is recommended that companies:

1. Obtain microbiological profiles of various cuts
2. Carry out shelf life trials on these cuts under controlled conditions in the company cold store
3. Focus on obtaining download data from importers, particularly in China
4. Relate high counts on various cuts with the range of temperature:time data profiles obtained from the importer

Supply to the Chinese market is expected to increase greatly and it would be prudent to revisit the type of information produced in the present study in the medium term. Such a study might be expected to identify potential problems which could be mitigated before such problems manifest themselves.

3.0 Introduction

Australia has been exporting meat to distant markets for over 170 years, first salted meat in the 1840s and then, with the advent of mechanical refrigeration, frozen meat. The first shipment in 1873 aboard the SS Norfolk spoiled when the refrigeration failed but the next trial aboard SS Strathleven arrived in London from Melbourne after 64 days at sea in excellent condition. Sensory testing was carried out at a lunch on board for one hundred and fifty and samples to Queen Victoria and the Prince of Wales also received the royal nod. A good start, but marred by a lack of knowledge how to thaw frozen meat meant the Australian trade had to take second place to South American chilled meat which could be landed after a 14-day voyage without any losses from drip. Frozen meat continued to be supplied from Australia until the middle of the 20th century though at a discount compared with chilled meat.

In the 1960s, because of advances in packaging films and technology, it became possible to reach distant markets with chilled, vacuum-packed (VP) primals and subprimals, a trade which has continued to flourish with Australia supplying more than 100 markets.

The basis of the vacuum-packed trade in primals is that the gaseous atmosphere in the bag prevents the growth of Gram-negative spoilers, allowing the biochemically-benign lactic acid bacteria to flourish. Other pre-requisites needed to optimise shelf life of vacuum-packed meats were identified by CSIRO researchers (Egan et al. 1988):

- An initial count no more than log 2-3 cfu/cm2
- Packaging film with low oxygen permeability
- Good control of temperature throughout the storage period

If these pre-requisites were met, Egan et al. (1988) predicted that shelf lives for lamb and beef stored at 0°C would be 42-56 days and 70-84 days, respectively. Shelf lives tended to the shorter end of the range when initial counts were higher than log 2-3 cfu/cm2 and when temperature control could not be guaranteed.

More recently, baseline studies of Australian meat since 1993 indicate significant improvement in the hygienic status of primals at packing so that, in 2011, the mean APC of beef striploins was log 1.25 cfu/cm2 while that of lamb shoulders was log 2.3 cfu/cm2 (Phillips et al. 2012a, b).

The ability to control the gaseous atmosphere around the meat via the oxygen transmission rate has become more reliable, both in terms of the oxygen transmission rate of the packaging films and of the packaging technology.

The optimum temperature for storage of vacuum-packed primals has been defined by Gill et al. (1988a) as -1.5±0.5°C. The same workers also established that small rises in temperature reduced shelf life significantly. For example, at 0°, 2° or 5°C the storage life is reduced by about 30, 50 or 70%, respectively, compared with storage at -1.5°C (Gill et al. 1988b).

Cold chain handling and technology have also improved, with air and sea freight both capable of maintaining product temperature close to the optimum established by Gill and co-workers. A range of advances in process hygiene and cold chain has resulted in significant increases in shelf lives of beef and lamb VP primals with Holdhus-Small et al. (2012) and Kiermeier et al. (2013) storing beef and lamb VP primals successfully just below 0°C for 220 days and 90 days, respectively.

However, in a review of factors affecting shelf life of vacuum-packed primals transported to distant markets, Mills et al. (2014) cited the introduction of “slow steaming” as a major negative factor.

The congruence of slow steaming, coupled with perceived problems associated with successfully servicing countries with potential cold chain difficulties in marketing chilled, VP meats was the initial stimulus for the present study, with terms of references to:

1. Provide information on shipping times to each major market
2. Evaluate temperature:time relationships during shipping to each market
3. Assess the effect of temperature:time on the microbiological profile and shelf-life during shipping

Development of the Terms of Reference (ToRs) for this project was undertaken in a climate of expectation that the China could become Australia’s major, if not the major, market. For example an Australian Financial Review article cited burgeoning exports of Australian beef and veal to China, and stated an opinion by ANZ’s director of agribusiness research, Michael Whitehead, that Australia’s beef exports to China could be worth $130 billion by 2023.

To facilitate export development to China the Department of Agriculture and water Resources (DAWR) has developed an Industry Standard for the Hygienic Production, Transportation and Distribution of Australian Chilled Meat to China.

The Standard contains parameters relevant to the present study stating that the shelf life for:

- *Chilled beef carcases and quarters will be no more than 21 days**
- *Chilled lamb and mutton carcases will be no more than 14 days**
- *Vacuum packaged beef will be no more than 120 days*
- *Vacuum packaged lamb and sheep meat will be no more than 80 days*

*When carcases are cut up into smaller meat pieces (primals, sub-primals or final cuts), the shelf life must be re-validated by the exporter, in consultation with the importer.

To meet the projected demand in China, Australian establishments are entering relationships with Chinese companies. One recent memorandum of understanding between Australian Country Choice (ACC) and Genius Link Asset Management (GLAM) underlines specific opportunities offered by the Chinese market for lower value meat cuts such as rib fillets and briskets. For exporters to China this presents challenges because little is known of the shelf life of meat cuts other than beef striploins and cube rolls Holdhus-Small et al. (2012) and of lamb legs and shoulders (Kiermeier et al. (2013).

In addition, a basic impediment to a successful VP chilled meat trade is a perceived loss of cold chain integrity within China, where McLellan (2016) has documented potential problems with maintaining cold chain integrity such as:

- Non-palletised deliveries
- Lack of loading/unloading docks

- Traffic congestion in CBDs causing delays in delivery
- Regulations restricting truck capacity in CBDs
- Costly maintenance of reefer units
- Limited skilled labour resources

The present study utilises information on Australia's markets and market chains from establishments by obtaining temperature:time records of container movements to major distant markets and entering the data into a software tool developed by the University of Tasmania (UTas) for predicting shelf life of VP chilled primals.

4.0 Project Objectives

The objectives of the present project are embodied in the ToRs, to:

1. Provide information on shipping times to each major market
2. Evaluate temperature:time relationships during shipping to each market
3. Assess the effect of temperature:time on the microbiological profile and shelf-life during shipping

5.0 Methodology

5.1 Temperature:time data

Some establishments include a data logger (TempTale®4USB, Sensitech) within the container, either in a carton or on the container wall near the doors. When the container is unloaded the logger can be downloaded to give two files: a temperature:time chart with key data to identify the consignment, plus a file which can be converted to an Excel file containing temperatures recorded at intervals during the journey from establishment to importer. Data loggers record temperature fluctuations and become important in the event of an insurance claim if the product arrives in an unacceptable state.

To inform the present study a number of establishments provided information to support the present project.

5.2 The UTas shelf life predictor

The predictor (Fig 1) has been configured to predict the time (in days) before meat “shows a noticeable loss of quality” of beef and sheep VP primals during chilled storage. For the purposes of this study “noticeable loss of quality” is equated with end of shelf life. Inputs required are:

- Starting bacterial count
- Temperature at each selected time interval

The shelf life remaining is illustrated on a graph and stated in boxes.

The tool can also be interrogated for “what-if?” scenarios by varying starting bacterial count or temperature:time fluctuations.

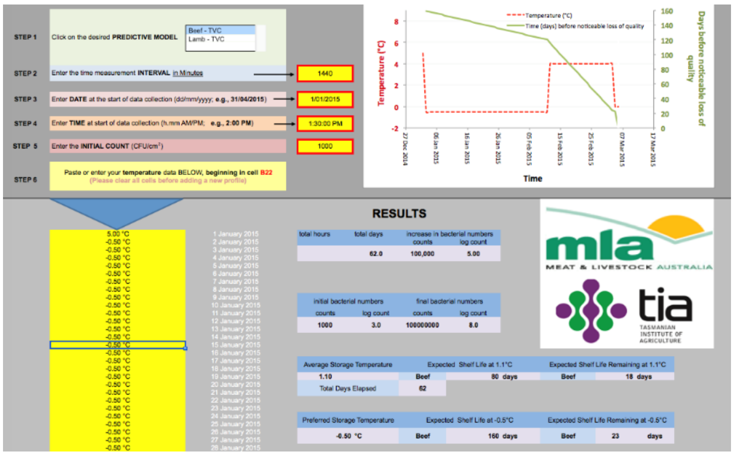


Fig 1: Interface of the UTas shelf life predictor

5.3 Bacterial inputs

The bacterial inputs used in this study are based on data from the 2011 baseline study for VP beef primals (striploins and outsides) and VP sheep primals (legs and shoulders). The data published by Phillips et al. (2012a, b) and summarised in Table 1 are expressed both as the log and arithmetic Aerobic

Plate Count (APC), the latter being necessary for insertion to the UTas predictor.

When inserting starting bacterial level at packing into the UTas tool, APCs of 100 (log 2) cfu/cm2 for beef and 1,000 (log 3) cfu/cm2 for sheep primals are used. These levels are slightly higher than the mean levels determined by Phillips et al. (2012a, b) and are used purposely to build some conservatism into estimates of end-of-trip bacterial levels and shelf life remaining for the purchaser.

Table 1: Aerobic Plate Counts (APCs) for beef and sheep vacuum packed primals (after (Phillips et al. 2012a, b)

	Concentration (log cfu/cm^2)				
	Mean	90th %-ile	95th %-ile	99th %-ile	Maximum
Beef					
Striploin	1.3 (20)**	2.6 (400)	3.1 (1260)	4.3 (20000)	5.3 200000)
Outside	1.5 (32)	2.9 (790)	3.2 (1590)	4.0 (10000)	4.2 (15900)
Sheep					
Leg	2.0 (100)	3.1 (1260)	3.5 (3160)	4.1 (12600)	4.6 (40000)
Shoulder	2.3 (200)	3.5 (3160)	4.2 (15900)	5.0 (100000)	6.2 (1580000)

*Limit of detection 0.08 cfu/ cm^2 ** Antilog

5.4 Interpreting TempTale data

The chart below (Fig 2) provides temperature data during a 45-day voyage from Melbourne to Southampton (UK). The mean temperature over the whole voyage was -0.6°C with slight increases when containers were off power on February 23 (loading in Melbourne), March 11 (unloading in Tanjung Pelepas), March 17 (reloading in Tanjung Pelepas), April 3 (unloading at Southampton) and April 6 (downloading of logger at customer's premises.

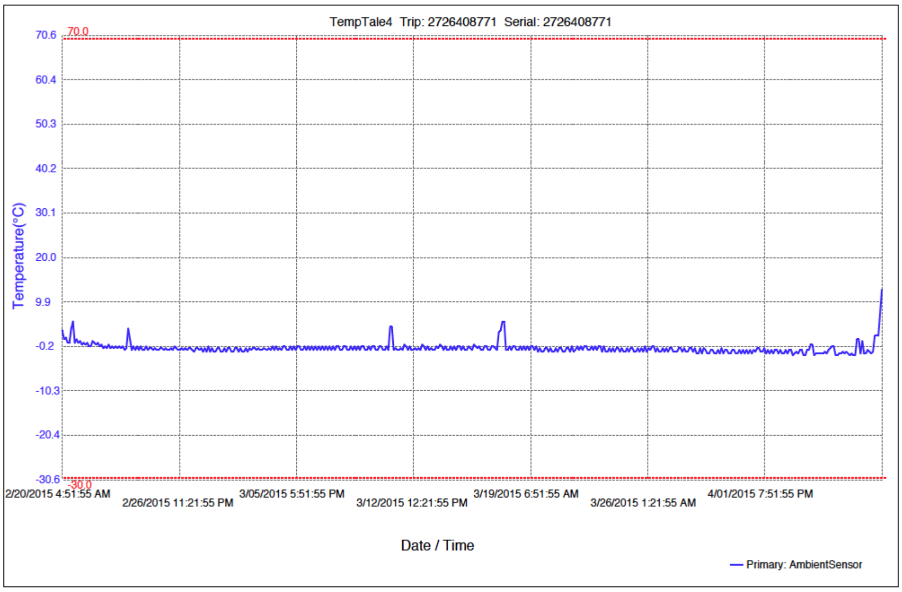


Fig 2: Temperature:time trace generated by TempTale data logger during voyage between Melbourne and the UK

6.0 Project Outcomes

The results of the present study are presented in three parts, aligning with the terms of reference:

Part 6.1: Provide information on shipping times to each major market
Part 6.2: Evaluate temperature:time relationships during shipping to each market
Part 6.3: Assess the effect of temperature:time on microbiological profile and shelf-life

6.1 Major markets and shipping times

While Australia exports VP chilled beef and lamb to many markets, the major ones are listed in Table 1 major of which are listed in Table 2.

Table 2: Export (t) of vacuum packed chilled meat to major markets 2013-14, 2014-15 (MLA data, 2016)

	Europe	Japan	Korea	Middle East	USA
Beef primals					
2013-14	22,266	113,235	32,578	18,903	48,880
2014-15	24,090	129,220	34,443	11,092	87,201
Lamb primals					
2013-14	6,220	3,403	209	10,429	23,253
2014-15	6,846	3,525	335	11,082	24,360

Chilled lamb carcases are also exported to the Middle East: 415t in 2013-14 and 620t in 2014-15.

6.1.1 Shipping by sea

A number of container lines service the Australian market, and publish schedules on the internet from can be constructed shipping times to ports of entry in each major market.

In Appendix 1 are presented typical shipping times (Tables A1-A16; Figs A1-A4) to Australia's major markets; a sample of which is summarised in Table 3, based on a Melbourne departure.

Table 3: Typical shipping times from Melbourne to major markets

Destination	Days	Shipper
Yantian (Shanghai)	20	Maersk
Philadelphia	37, 38	Maersk, Hamburg Süd
Long Beach (Los Angeles)	31*	Maersk
	33	Hamburg Süd
	27	Hapag Lloyd
Rotterdam	45**	Hamburg Süd
	49	Marfret
	51***	Hapag Lloyd
	40****	Maersk
Yokohama	17	Maersk
	16	Hamburg Süd
	16	Hapag Lloyd
Jeddah	33****	Maersk
	26***	Hanjin Shipping

Jebel Ali Dubai	23****	Maersk
	26***	Hanjin Shipping

* Trans-ship in Yokohama (Japan)

** Trans-ship in Cartagena (Colombia)

*** Trans-ship in Singapore

**** Trans-ship in Tanjung Pelepas (Malaysia)

Routes listed in Table 3 include direct routes where the container remains on the same vessel until it reaches its destination, and routes which involve trans-shipment involving unloading onto a second vessel. Each shipping line operates a network of vessels which, according to schedule, will meet at trans-shipment ports with minimal delay.

Some shipping companies book the container for all of the vessels involved in its journey and, if delays are foreseen (e.g. bad weather) adjust the speed of vessels in an effort to synchronise arrivals at the trans-shipment port. The practice of slow steaming makes it possible for vessels to increase their speed to offset delays. In addition, shipping lines will attempt to unload those containers first which are needed for their second vessel involved in the trans-shipment.

On occasion, however, a scheduled trans-shipment will be missed, in which case the container will wait for the next available vessel, probably from the same shipping line – a delay which often incurs the container waiting 7-8 days at dockside, connected to refrigeration.

A typical voyage log from release of the container for loading at the establishment to transhipping and final unloading at the destination is reproduced in Table 4. Each voyage begins with the shipping company releasing a specific container to the meat establishment for loading and it can be seen from Table 4 that the loaded container was delivered to Fremantle eight days after receival. After loading one day after receival, and departure soon after, the vessel docked in Singapore after a voyage of almost six days. The next six days were spent under refrigeration dockside awaiting the arrival of the Hanjin Hungary and, after a further 11 days at sea was unloaded in Jeddah (Saudi Arabia) approximately 27 days after container loading at the meat establishment.

Table 4: Typical movements of containers during loading, trans-shipment and unloading (shipping company information provided to the establishment)

Status	Location	Event date
Empty Container Release to Shipper	Fremantle (Qube Logistics)	2015-11-18 12:51
Loaded on Margaret River Bridge	Fremantle (Patrick Stevedores)	2015-11-27 20:26
Margaret River Bridge departs	Fremantle (Patrick Stevedores)	2015-11-28 00:05
Margaret River Bridge arrives	Singapore (PSA Corporation)	2015-12-03 19:00
Margaret River Bridge berths	Singapore (PSA Corporation)	2015-12-03 20:00
Unloading Margaret River Bridge	Singapore (PSA Corporation)	2015-12-04 02:58
Loaded on Hanjin Hungary	Singapore (PSA Corporation)	2015-12-10 07:54
Hanjin Hungary departs	Singapore (PSA Corporation)	2015-12-10 14:10
Hanjin Hungary arrives	Jeddah, Saudi Arabia	2015-12-21 05:00
Hanjin Hungary berths	Jeddah, Saudi Arabia	2015-12-21 12:00
Unloading Hanjin Hungary	Jeddah, Saudi Arabia	2015-12-22 04:31
Container leaves inbound terminal	Jeddah, Saudi Arabia	2015-12-29 17:00

As will be developed in a later section, trans-shipping of VP lamb primals in particular to the Middle East is an extremely important event, given the requirement of some governments that product be delivered with more than half the recognised shelf life available. A missed trans-shipment in Singapore or Tanjung Pelepas may compromise a consignment and there is anecdotal evidence that a delay results in automatic discounting of the consignment.

6.1.2 Shipping by air

Australian establishments air freight VP chilled meats and chilled carcases. In the case of the latter, airfreight is the only option in Middle Eastern markets because of a requirement that more than 50% of the shelf life remains (from the date of processing) at the time of unloading at the destination.

The airfreight sector uses Unit Load Devices (ULDs) to maximise product packing and minimise time of loading and unloading. Airfreight containers are available in several sizes and are designed to fit in the cargo hold of either narrow- or wide-bodied aircraft.

Typically, carcases are transported from the processing plant to the freight forwarder for loading into a ULD within 24 hours of slaughter and dressing. At the freight forwarder the ULD is lined with an insulating blanket (Fig 3), a carpet of dry ice is laid, product is loaded and dry ice in cartons (ca 50kg) added on top of product (Fig 4).

Fig 3: Insulated interior of UDL

Fig 4: Carcases with dry ice in containers on top of stack

Cartoned meats are loaded in similar manner to carcases except loading the ULD may be done at the processing plant, in which case loading and transport is scheduled so that the ULD is delivered to the freight forwarders about 3 hours prior to departure of the aircraft.

Typically, chilled cartooned meat destined for Europe is transshipped via a Middle East airport (Dubai, Doha or Abu Dhabi) where tarmac temperatures regularly exceed 50°C. Precautions to minimise temperature rises of product in UDLs during unloading and transhipping include the use of “Cold Dollies” (Figs 5, 6, 7). Viessmann Technologies manufacture the ICEWHEELER AIR cooling dolly, facilitates transfer from aircraft to airport refrigeration facilities and also act as temporary cold storage for short transshipment times.

Flights from east coast airports to destinations in the UAE are frequent and around 15 hours. There are frequent connections from UAE airports (Dubai and Abu Dhabi) to Middle Eastern (e.g. Amman, Jordan ca. 3 hours) and European destinations (e.g. London ca. 7 hours).

Fig 5: Viessmann Technologies cooling dolly

Fig 6: Roll-in-roll-out via two doors

Fig 7: Cold dolly as used by Emirates

6.2 Evaluate temperature:time relationships during shipping

Evaluation of temperature:time relations during shipping to a market are achieved using the outputs of the TempTale logger which accompanied the voyage. Two outputs are downloadable: a temperature:time chart with summary data and an Excel file.

Fig 8 illustrates a voyage from an establishment in WA to a French customer where the mean temperature for the voyage was -0.4°C with a standard deviation of +/- 0.5°C.

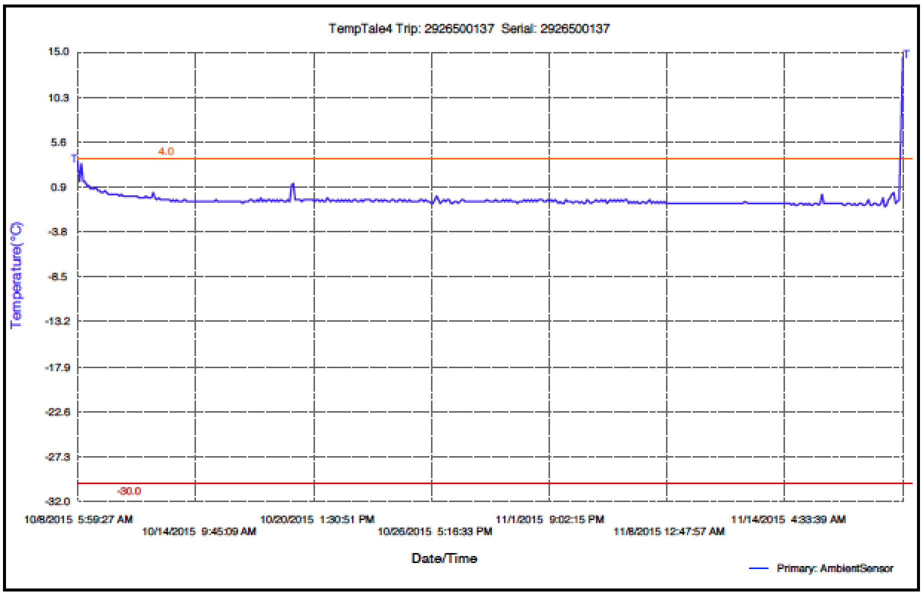


Fig 8: TempTale logger information from a container between Fremantle and Le Havre (France)

A second output can be converted to an Excel file containing temperature measurements at specified intervals during the voyage. This file can be modified for entry into the UTas predictor to gain information on shelf life used during the voyage, plus predicted shelf life remaining at a specified storage temperature. For the present trip the predicted shelf life remaining at 4°C storage was 8 days.

Interpretation of the trip can be enhanced if trip information is obtained from the shippers, as presented in Fig 9. This information may be used to account precisely for "blips" in temperature during loading (October 12), trans-shipping at Tanjung Pelepas (October 19 and October 27), unloading at Le Havre (November 16) and downloading of the data logger at the French establishment (November 20).

It is unfortunate that not every shipment data set obtained from establishments for the present study included the three elements cited above. Without the trip record as set out in Fig 9 identifying key points is more difficult, though establishments have information which can be helpful, for example the Estimated Time of Departure (ETD) and Estimated Time of Arrival (ETA).

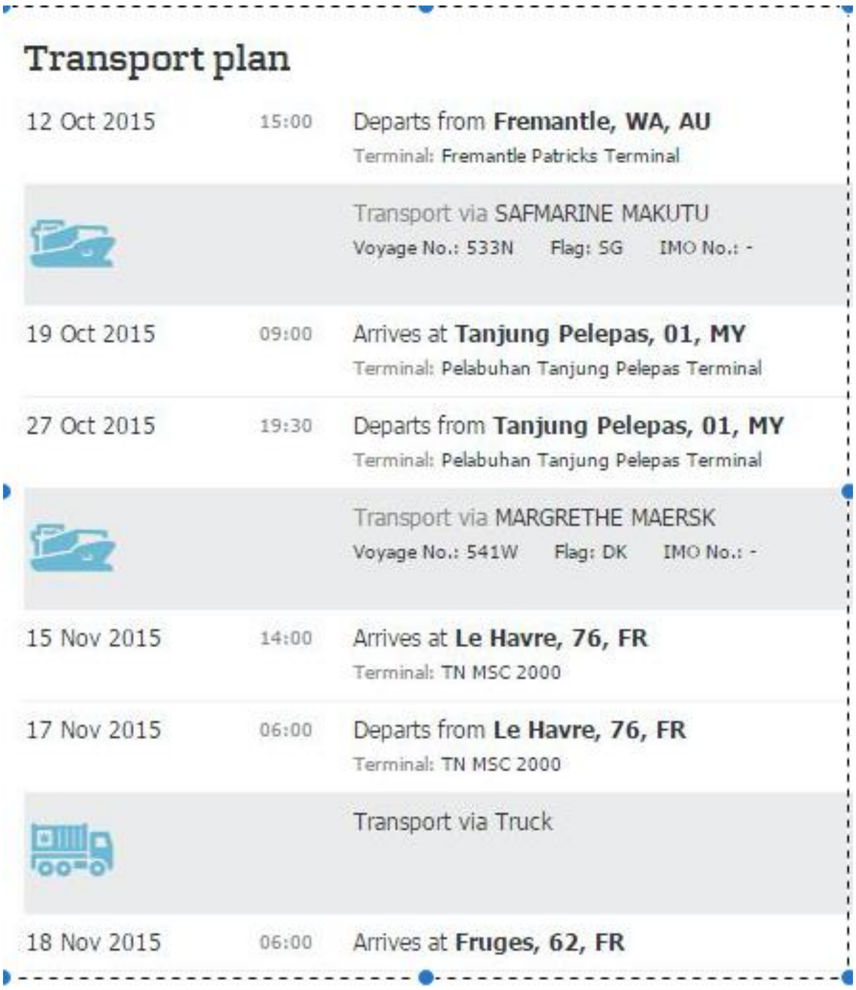


Fig 9: Temperature fluctuations during shipping establishment to Europe

6.3 Assess the effect of temperature:time on microbiological profile and shelf-life

The effect of temperature and time on the microbiological profile and shelf life of VP primals is considered by examining voyages to each market and making an assessment of whether the voyage had been "good" or "bad".

For the purposes of this study a good voyage is defined as one in which:

1. Product spends minimum time at the Australian establishment prior to loading the container e.g. killed Wednesday, boned Thursday, loaded out Friday
2. Product is loaded into the container close to 0°C
3. Load out aligns with loading and embarkation of the vessel
4. Air is supplied to the container at the specified temperature e.g. -1°C
5. Trans-shipment is achieved with minimum delay
6. There is no interruption to supply of refrigeration during the voyage
7. At destination, product is unloaded promptly
8. Transport to the purchaser's cold store maintains a low temperature without freezing

Such voyages lead to ample time to market product through the retail chain, as determined by the shelf life remaining at an average of 4°C.

By contrast, on bad voyages:

1. At small establishments some orders may require 1-2 weeks until there is sufficient product to fill a container
2. Product loaded at 2-3°C will require some time to pull down close to zero
3. Losses in refrigeration occur due to breakdowns at sea or during power-off at unloading and trans-shipment.
4. Industrial action at the destination port may incur added time at sea
5. Land transport from a diversion port to the purchaser's cold store may add several days
6. To offset extended land transport the vehicle refrigeration may be set well below zero and partially freeze product

Such voyages result in the shelf life remaining for marketing through the retail chain being compromised. All of these aspects have been recorded during the present study and will be amplified in this section. Summary temperatures from all voyages monitored in this study are presented in Table 5.

Table 5: Summary temperature statistics for all containers monitored in this study

	Mean temperature for voyage (°C)
Sea containers (n=140)	
Mean	-0.17
Standard error +/-	0.7
Minimum	-1.8
Maximum	1.9
Air freight (n=48)	
Mean	0.6
Standard error +/-	1.9
Minimum	-4.7
Maximum	6.2

A range of -1.8°C to +1.9°C and a mean of -0.17°C would probably be regarded as a suitable performance for sending chilled VP meat by sea to distant markets. However, as can be seen from Table 6, on longer voyages (ca. 50 days from the establishment's chiller to that of the purchaser) the shelf life of lamb primals is exhausted at +1.9°C and only 8 days remains for marketing and retailing of beef primals.

Table 6: Shelf life remaining at 4°C following voyages at the range of temperatures

		Shelf life remaining at 4°C	
Journey length (d)	Average temperature (°C)	Lamb primals	Beef primals
50	+1.9	None	8
50	-1.8	28	36

Variables influencing shelf life are considered in the following section on a market-by-market basis.

6.3.1a Air freight of lamb carcases and primals to the Middle East

A market exists both for carcases (see Fig 4) and cartons of VP primals with a number of airports being served by direct flights from Australia, particularly Dubai, Abu Dhabi and Doha; there are regular onward flights from these hubs to other Middle Eastern markets e.g. Jordan, Bahrain.

Industry information suggests that VP primals are distributed via the importer's cold store to hotels and supermarkets while carcases are sold directly from refrigerated trucks both to smaller operators.

Based on a small number of loggers, typical flight times from Melbourne to Amman (Jordan) were around 1 day,19 hours with mean temperatures between -2.1 and +0.1°C; final predicted TVC of log 3.1-3.3 cfu/cm2 and 25 days shelf life available at 4°C.

6.3.1b Air freight of lamb primals to Europe

A number of trip records between Australia and continental Europe have been evaluated via the United Arab Emirates, Qatar and Hong Kong. A typical good trip is shown in Fig 10 where the temperature in the carton is maintained close to 0°C for the entire trip without great variation.

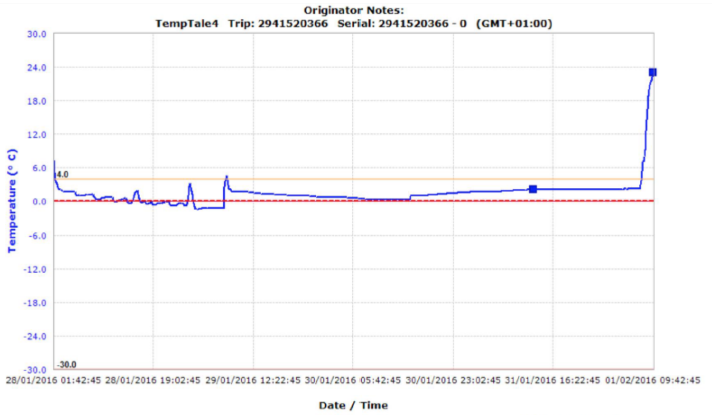


Fig 10: Temperature changes during shipment of chilled lamb primals from Australia to Europe

Key events in the transport of this shipment are identified in Table 7 and indicate that dry ice added by the freight forwarder maintained temperature throughout the journey, particularly during trans-shipping at the Middle Eastern airport.

A summary of fourteen consignments is presented in Table 8 which shows the influence of temperature on the bacterial level at unloading in Europe, plus the remaining days shelf life available if the product is stored at an average of 4°C for the remainder of its life. It should be noted that a starting bacterial level of 1,000 cfu/cm2 (log 3 cfu/cm2) was used.

Table 7: Key events and timeline during shipment to Europe

Day	Date	Approximate time	Activity
Sunday	23/07/15	05:30:00	Container loading
Sunday	23/07/15	22:00:00	Arrival at freight forwarder
Monday	24/07/15	03:00:00	Addition of dry ice to product in UDL
Monday	24/07/15	13:00:00	Take-off Australia
Tuesday	25/07/15	05:00:00	Landing in Middle East
Tuesday	25/07/15	06:00:00	Unloading and holding
Tuesday	25/07/15	14:00:00	Loading and take-off
Tuesday	25/07/15	22:00:00	Arrival Europe
Tuesday	25/07/15	23:00:00	Unload, transport to cold storage

Thursday	27/07/15	08:00:00	Removal of logger

Although some consignments were not optimal e.g. either "warm" (average 6.2°C) or "cold" (-4.7°C), it should be emphasised that no complaint from any consignment was raised by the customer, which indicates that when cartons were opened at their final destination individual cuts presented acceptably.

Table 8: Summary data (n=14) for air freight of sheep primals from Australia to Europe

	Mean	Shortest*/Lowest**	Longest*/Highest**
Voyage length (d)*	3.7	1.9	10
Average temperature on voyage (°C)**	0.7	-4.7	6.2
Final bacterial level (log cfu/cm2)**	3.9	3.1	5.9
Shelf life remaining at 4°C (d)*	22.8	18	25

Summary: air freight to the Middle East and Europe

From the foregoing it is clear that a satisfactory supply chain exists to the Middle East and Europe. Precautions such as the use of a thermal blanket, addition of dry ice and use of cold dollies during trans-shipment are generally effective even when flight delays extend the journey. The trips presented in Table 8, which had origins from several Australian airports, via Asian and Middle Eastern airports, terminating in Europe, ranged from 1.9 days to 10 days, implying that the latter missed a connection; apparently product arrived in satisfactory condition due to its average temperature of 2.7°C over the journey.

Missed connections sometimes result in overt spoilage as in the case illustrated in Fig 11 where it is thought that product missed a Middle Eastern connection to Europe and also underwent significant temperature abuse. Unfortunately a data logger record is not available to inform on the extent of the temperature abuse needed to cause blown pack spoilage.

Fig 11: Blown pack spoilage of VP lamb leg

6.3.2 Sea freight to Japan

From Table A2 it can be seen that the Australia-Japan journey is around 20 days from Melbourne to Japan (Osaka or Yokohama). Information from a Japanese importer (summarised in Table 9) states that product resides in the Japanese cold store/processing facility and is packed and released over the next 3-7 days for a final two-day retail period with a shelf life displayed at 72h.

The overall length of the cold chain varied between 22 and 30 days, to which should be added two days for slaughter and boning/packing in Australia.

Table 9: Typical cold chain from Australian meat establishment to Japanese supermarket

	Days	
	Minimum	Maximum
Container loading	0	0
Transport to vessel	1	2
Voyage to Japan	16	19
Customer cold store	3	7
Supermarket	2	2
Total	22	30

In Table 10 are presented summary data for twenty-five consignments from Australia to Japan. Average temperatures during door-door transport (Australia-Japan) varied between -1.8°C and +0.72°C with small blips in Australia and Japan when the container was off power during loading and unloading. Product arrived in the purchaser's cool store with a predicted 27-33 days shelf life for beef primals and 13-21 days for sheep primals remaining if the storage temperature averaged at 4°C.

Table 10: Summary data (n=25) for transport of vacuum packed primals from Australia to Japan customer cold store

	Mean	Shortest*/Lowest**	Longest*/Highest**
Voyage length (d)*	24.3	19	29
Average temperature on voyage (°C)**	-0.71	-1.8	0.72
Lamb primals (n=11)			
Final bacterial level (log cfu/cm2) **	5.5	4.5	6.5
Shelf life remaining at 4°C (d)*	18.5	13	21
Beef primals (n=14)			
Final bacterial level (log cfu/cm2) **	4.2	3.4	5.3
Shelf life remaining at 4°C (d)*	31	27	33

Based on a starting level of log 2 cfu/cm2 for beef primals and log 3 cfu/cm2 for sheep primals, predicted levels at arrival in-store in Japan were log 3.4-log 5.3 for beef primals and log 4.5-6.5 cfu/cm2 for sheep primals.

One major Japanese purchaser imposes a bacterial criterion for APC at entry to their cold store of log 5.7 cfu/cm2, a criterion which is believed to allow safe retailing over two days on display and a displayed shelf life of 72 hours on the packaging.

In the present context the fourteen consignments of beef primals all conformed with the company's specification for APC. By contrast 4/11 consignments of chilled lamb from Australia to Japan had predicted bacterial levels of log 6.0-7.4 cfu/cm2, which is in excess of the specifications of at least one Japanese purchaser.

Summary: Sea freight to Japan

Voyages between Australia and Japan present little opportunity for "bad" trips: no trans-shipment and good infrastructure in-country means product will usually be retailed usually no longer than 30 days after production in Australia.

6.3.3 Sea freight to Europe

Three companies supplied data loggers from consignments of VP lamb to Europe. Summary data (Table 11) indicate mean product temperatures ranged from -1.1 to +1.9°C, final predicted bacterial levels from log 6.8-8.0 cfu/cm2, and predicted shelf lives at 4°C from 0-30 days.

Australia-Europe routes are the longest and may involve trans-shipment in Singapore or Tanjung Pelepas for westbound voyages, or in Cartagena (Colombia) for eastbound voyages, resulting in an establishment chiller to customer chiller time up to 54 days. As may be seen from Table 4.3.7 predicted shelf life for some consignments was zero, resulting from long voyages (48 days) and "warm" temperatures (+1.9°C and +1.3°C). It should be emphasised that both consignments were accepted by the customer without any negative response.

Table 11: Summary data (n=21) transport of lamb primals from Australia to customers' cold stores in Europe

	Mean	Shortest*/Lowest**	Longest*/Highest**
Voyage length (d)*	45.3	39	54
Mean voyage temperature (°C)**	-0.35	-1.1	1.9
Final bacterial level (log cfu/cm2)**	7.3	4.5	8.0
Shelf life remaining at 4°C (d)*	13	0	30

Summary: sea freight to Europe

Voyages between Australia and Europe present some opportunity for "bad" trips because of the need for trans-shipment and consequent occasional very long voyage times; VP lamb primals are more vulnerable than beef primals, particularly if the mean temperature is above 0°C.

6.3.4 Sea freight to Middle East

In Table 12 are presented summary data for six voyages between Fremantle and Jeddah, Saudi Arabia, with a door-to-door time between supplier and customer around five weeks. Average product temperatures varied between -0.5°C and 1.9°C with a maximum remaining shelf life at 4°C being 18 days and 6 days, respectively.

Table 12: Summary data transport of lamb primals from Australia to customers' cold stores in the Middle East (n=6)

	Mean	Shortest*/Lowest**	Longest*/Highest**
Voyage length (d)*	33.5	31	37
Mean voyage temperature (°C)**	0.8	-0.5	1.9
Final bacterial level (log cfu/cm2) **	7.5	5.5	8
Shelf life remaining at 4°C (d)*	10.5	6	18

As can be seen from Fig 12 voyages typically involve trans-shipment in either Singapore or Tanjung Pelepas, around nine days after leaving Fremantle, with a residence time there of 4-8 days before reloading, then interim docking in one of the Gulf States after a further fourteen days.

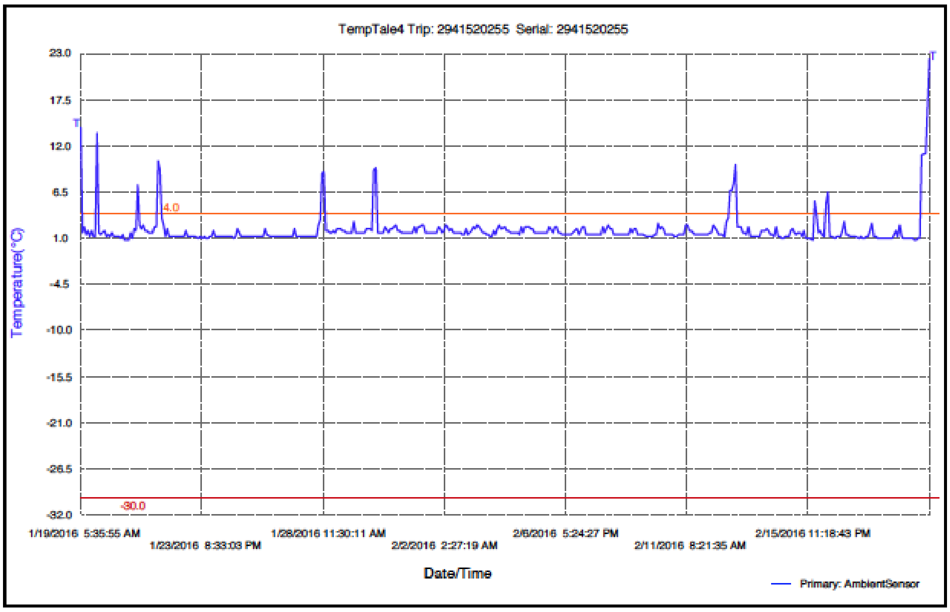


Fig 12: Temperature profile of typical voyage Fremantle-Jeddah (Saudi Arabia)

Summary: sea freight to the Middle East

The above data indicate that shipment of lamb primals generally occurs at a suitably low temperature to conform with standards prescribed by the importing countries. As outlined in the MLA publication "Shelf life of Australian red meat", the Gulf Cooperation Council (GCC) has developed a large number of standards covering the following countries:

• Kingdom of Bahrain

• Kuwait

• Sultanate of Oman

• Qatar

• Kingdom of Saudi Arabia (KSA)

• United Arab Emirates (UAE)

There are two standards relevant to the present data (above):

1. *Expiry dates mandated in the Gulf Standards Organisation Standard (GSO 150/2007 Expiration periods of Food Products): Vacuum-packed meat stored at -0.5° to 0°C: no more than 70 days … from the date of slaughter.*

2. *The United Arab Emirates also imposes a microbiological criterion for Aerobic Plate Count of n=5, c=3, m=106 and M=107, which applies to all chilled meat (AQIS Market Access Advice 1025, 2010).*

6.3.5 Sea freight to USA

As can be seen from Appendix 1, scheduled voyages from Australia's east coast to USA west coast vary according to routing from 21-35 days, with a scheduled time to Long Beach and Oakland California averaging 24-27 days.

During the present study, 80 voyages over the period November 2014-February 2016 were studied. For much of this time trade to west coast USA was disrupted by industrial action between members of the International Longshoremen and Warehouse Union and waterfront employers. The action began on July 1, 2014 and affected shipping at ports in California, Oregon and Washington, which collectively clear 68% of all container shipments to USA. Total voyage length (from establishment cold store to clearing) was around 10 days longer during the dispute, compared with "normal" docking and clearing. Resolution of the dispute and return to normal clearing of containers to west coast customers took most of 2015.

Two establishments provided temperature:time data plus ETD and ETA dates for 80 voyages, Establishment A supplying beef primals, mainly during the dispute and Establishment B supplying lamb primals after the dispute was resolved.

For Establishment A, total trip length to customer cold store averaged 48.5 days, ranging from 42-57 days. Length of time between container loading in Australia and departure of the vessel varied between 2-21 days (mean 7.1 days) and unloading/clearing time in California from 4-15 days with a mean of 8.9 days.

The period studied indicates great variation in time required in every phase of the voyage: container loading, ETDs and ETAs, unloading in California and clearing to the customer. In addition, land transport in the USA was 1100 km from Long Beach/Oakland to the customer's Utah processing plant. Unsurprisingly, shelf lives of landed product varied greatly, from 14-29 days at 4°C.

Table 13: Summary data (n=70) for transport of VP beef primals from Establishment A cold store in Australia to USA cold store (December 2014-January 2016)

	Mean	Shortest*/Lowest**	Longest*/Highest**
Scheduled voyage length (d)*	24.1	20	28
Actual voyage length (d)*	31.8	23	45
Unloading/clearing/land transport (d)*	8.9	4	15
Total transport time (d)	48.5	42	57
Average temperature on voyage (°C)**	0.1	-0.2	1.6
Final bacterial level (log cfu/cm2) **	6.1	4.7	8
Shelf life remaining at 4°C (d)*	24	14	29

Post-dispute shipments to west coast USA from Establishment B are summarised in Table 14 and indicate voyage and clearing times much shorter than those during the dispute. Mean average temperature in the carton varied from -1.77 to -0.03°C, predicted final bacterial levels from log 5.1-7.4 cfu/cm2, and available shelf-life from 14-20 days at 4°C.

Table 14: Summary data (n=10) transport of VP lamb primals from Establishment B cold store in Australia to USA cold store (December 2015-February 2016)

	Mean	Shortest*/Lowest**	Longest*/Highest**
Preloading time (d)*	2	1.5	4
Actual voyage length (d)*	27	26	30
Unloading/clearing/land transport (d)*	3	2	4
Total transport time (d)*	34.2	33	36
Mean voyage temperature (°C)**	-0.9	-1.77	-0.03
Final bacterial level (log cfu/cm2) **	6.0	5.1	7.4
Shelf life remaining at 4°C (d)*	17.2	14	20

Summary-sea freight to USA

In terms of shelf life remaining, voyages between Australia and west coast USA benefit from needing no trans-shipment and from having good in-country infrastructure. However, the effect of waterfront disputes is exemplified by around ten extra days being required to transport and clear containers, and its effect on available remaining shelf life.

6.3.6 Sea freight to China

The export of chilled beef to China is of relatively recent origin and is touted to grow rapidly from the relatively small volumes cited in Table 15; note imports of chilled lamb have been almost zero in recent years.

Of importance to Australian exporters is the predilection for lower-value meat cuts, a factor emphasised by Australian Country Choice managing director, David Foote, in an interview with ABC Rural (ABC, 2016), citing specific opportunities for various cuts such as rib fillets and briskets adding that China was not a steak market.

There are reports that refrigerated storage and distribution in China are in being developed in an effort to accommodate increased demand for chilled foods in general from a wide range of importing countries. Inconsistent refrigeration capacity plus the requirement to transport to outer provinces on road journeys up to 2,500km and several days present challenges to exporters of chilled meat.

Anecdotal evidence is that the bulk of meat imported from Australia enters the food service trade in China, where it may be consumed over a period extending to 60-90 days which, coupled with the time required from slaughter to delivery in-store in China (ca. 30 days) may take the product close to the shelf life label of 120 days.

Table 15: Exports of chilled meat (t) to China (MLA data)

	2014	2015	2016*
Blade	552	839	615
Brisket	412	843	505
Chuck	70	139	255
Chuck roll	46	331	127
Cube roll	58	310	188
Ribs	66	89	302
Rump	79	260	73
Shin shank	334	626	745
Silverside/outside	297	642	719
Striploin	215	420	327

Thick flank/knuckle	331	711	605
Thin flank	158	275	288
Topside/inside	101	252	485
Other	440	364	420
Total	3159	6101	5654

* July 2015-March 2016

For the present project enquiry was made of companies with licenses to export chilled meat to China of whether they used data loggers in their consignments. Responses were as follows:

- No response (2)
- Don't use a logger (7)
- Use a logger with each consignment (1)

The latter company was thorough in its efforts to monitor product from establishment to final destination in several shipment in February-April, 2016 (Table 16) and each carton containing a logger was labelled and denoted by fluorescent tape.

Table 16: Information for Chinese importer regarding data loggers in consignments

Date / Shift	Container	Position	Logger #
29/02/16 - 2	SZLU 9620453	3rd row	2718541995
29/02/16 - 2	SZLU 9620453	3/4 loaded	2718541968
04/03/16 - 1	MSCU 7441792	1st row top left	2718541948
04/03/16 - 1	MSCU 7441792	3/4/ loaded centre	2718541913
11/03/16-2	MMAU1209520	Centre of 3rd row	2716511094
11/03/16-2	MMAU1209520	Centre of 26th row	271651108
17/03/16-1	TTNU 8145312	10th row centre bottom	2716511070
17/03/16-1	TTNU 8145313	16th row top left	2716511097
24/03/16-2	CXRU1202552	2nd row middle	2941517802
24/03/16-2	CXRU1202552	Centre 3/4 loaded	2941517805
07/04/16-1	EISU 5706849	Rear/top left	2941517713
07/04/16-1	EISU 5706849	Front/bottom left	2941517793
07/04/16-1	EISU 5706849	1/2 loaded centre	2941517754

Six loggers were recovered, downloaded and summary data are presented in Table 17.

Table 17: Summary, temperature:time relations from the establishment cold store in Australia and holding period in importer's cold store in Shanghai

	Mean	Shortest*/Lowest**	Longest*/Highest**
Preloading, voyage, clearing (d)*	25	17	34
Storage in China cold store (d)*	19	2	29
Mean cold chain temperature (°C)**	-0.8	-1.5	0.4
Final bacterial level (log cfu/cm2) **	4.5	3.0	6.5

The data in Table 17 take into account the total time taken from preloading the container at the Australian establishment to release of product to the market in China i.e. includes a holding phase in the importer's cold store.

Based on the data gathered for consignments from one Australian establishment to a single Chinese importer the cold chain was maintained in the latter's cold store, with a mean temperature of -0.8°C over the entire cold chain until release of product from the importer. This resulted in generally low bacterial levels in product being delivered to customers (mean log 4.5 cfu/cm2) being predicted.

In January 2016 the Australian industry provided Chilled Meat Supply Chain seminars in China to importers and gained feedback as to how long importers considered they needed to use a chilled consignment. The information (Fig 13) confirms the belief that extremely long shelf lives are expected of Australian chilled beef, temperature fluctuations through the cold chain notwithstanding.

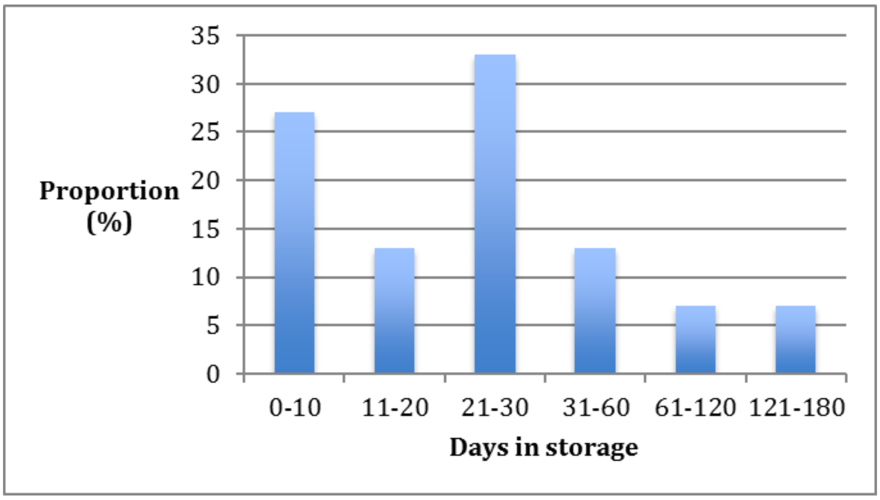


Fig 13: Expectations of Chinese importers on time needed to utilise a consignment of chilled meat from Australia

Chinese importers also listed perceived impediments to using chilled beef including:

- The storage and logistic facility are not mature enough
- Market competition
- No existing selling channel

- Hard to operate and control
- Hard to source the product
- The selling channel is not professional
- The risk is too high as the logistic system in China is not mature
- The logistic and storage are problems
- Without processing condition to keep the product quality, they are considering pre-pack product.

Clearly there are serious logistical challenges in exporting chilled VP beef primals to China and possible storage temperatures are summarised in Table 18, which links data presented in Table 17 with predicted shelf life, as a function of temperature is the retail/food service phases of Australian product.

Table 18: The influence of in-country storage temperatures on shelf life remaining for utilisation

	Mean	Shortest*/Lowest**	Longest*/Highest**
Shelf life remaining at 2°C (d)*	51	39	59
Shelf life remaining at 4°C (d)*	30	23	35
Shelf life remaining at 6°C (d)*	19	15	23
Shelf life remaining at 8°C (d)*	14	10	16

Summary

Based on data presented from one establishment shipping to one importer, the cold chain was maintained. However, as can be seen from Table 18, shelf life at temperatures considered abusive in many countries (>4°C), is short and may not meet the expectations of some importers (see Fig 13).

7.0 Discussion

The present study indicates that numerous factors influence the shelf life available for the purchaser after transport from the Australian establishment:

1. Starting bacteria level at vacuum packing
2. Temperature and time product is stored before loading aboard the vessel
3. Power-off during breakdown aboard the vessel, or at loading/unloading
4. Slow steaming
5. Journeys extended by disputes or missed trans-shipment connection
6. Container set point delivers "warm" temperature over whole voyage
7. Macro temperature abuse during airfreight, both "warm" and "cold" abuse

7.1 Starting bacteria level at vacuum packing

In a container load of primals there will be a range of bacterial counts, one reliable estimate of which is that of Phillips et al. (2012a, b) based on a national baseline survey of 1144 beef primals (striploins and cube rolls) and 1226 sheep primals (legs and shoulders) - summarised in Table 19.

In the present study, when setting bacterial level at packing, APCs of 100 (log 2) cfu/cm2 for beef and 1,000 (log 3) cfu/cm2 for sheep primals have been used which, while slightly higher than the mean levels determined by Phillips et al. (2012a, b), build some conservatism into estimates of end-of-trip levels.

Clearly, longer voyages present the greatest potential for bacterial growth, such as from Australia to Europe. When the data in Table 1, which cover the entire distribution of APCs determined in the national baseline study, are inserted in the UTas predictor the predicted shelf lives for this voyage of VP primals are as presented in Table 19 and illustrate the effect which starting bacterial load has on predicted shelf life.

Table 19: Predicted shelf lives remaining at 4°C after a 45-day voyage with a mean temperature of -0.3°C for VP primals with various starting APCs

	Concentration (log cfu/cm2)			
	100	1,000	10,000	100,000
Beef	27	24	21	18
Sheep	14	12	10	7

7.2 Temperature and time product is stored before loading aboard the vessel

Ideally, orders are filled with minimum time between slaughter and departure of the aircraft/vessel. For example, A typical example is Establishment A, which slaughters sheep every Wednesday, bones and packs on Thursday, loads to the freight forwarder on Friday for air freight same day to Europe and pick-up by the customer on Monday.

For sea freight the container is ordered from the shipping company, filled promptly after it arrives for immediate transport to the docks and loading aboard the container vessel.

At some establishments, however, there may be departures from the regime described above due to reasons that include:

- Processing problems which delay container loading
- Disruption to vessel schedules

Fig 14 represents an establishment's profile of time elapsing between activating the data logger and loading the container aboard the vessel. It should be explained that this establishment were servicing an American customer throughout the dispute on the West coast of the USA, which may explain the extended times prior to loading aboard the vessel.

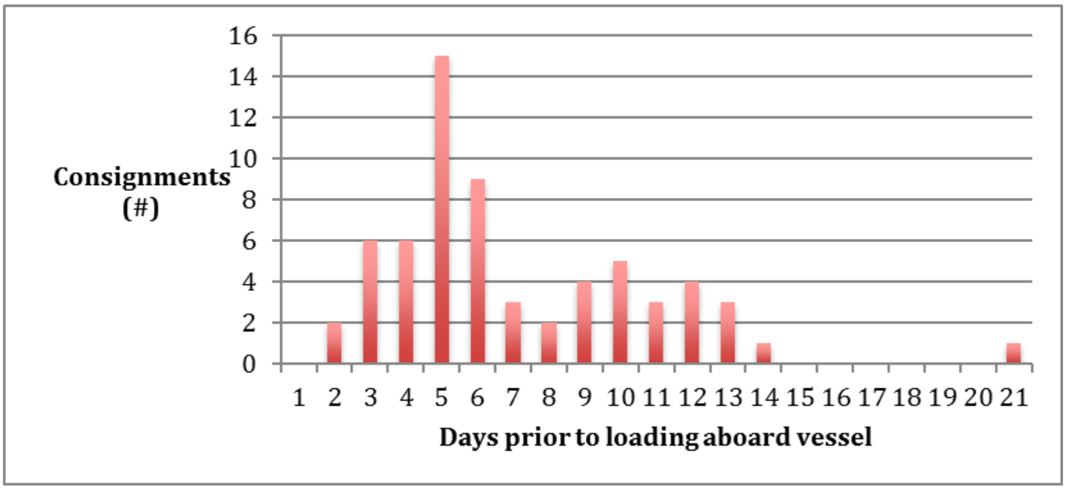


Fig 14: Profile of time elapsing from activating the logger to loading container aboard the vessel

7.3 Power-off during breakdown aboard the vessel, or at loading/unloading

Power must be removed during loading and unloading of containers at dockside, indicated by a sharp temperature peak on the TempTale chart, which as seen in Fig 15, was located on the container wall near the door.

Fig 15: Location of TempTale data logger

As can be seen from Fig 16 there are four temperature peaks: at loading in home and destination ports, plus trans shipment in Singapore. As well there was a significant temperature increase over 2-3 days during the early part of the voyage indicating a temporary loss of refrigeration to the container. Because of its location, the TempTale logger responded to changes in temperature at the container wall during passage through equatorial waters; such changes probably had significantly less effect on the vast majority of cartons in the container.

The consignment required 60 days door-to-door, over which time the air temperature averaged 0.28°C. If this temperature were identical with that of meat within cartons the bacterial level exceeded log 8 cfu/cm2 and the remaining shelf life would have been 16 days at 4°C. Had the container not lost refrigeration the average temperature would have been -0.25°C, the bacterial level at entry to the customer's cold store would have been log 6.2 cfu/cm2 with 23 days shelf life remaining at 4°C.

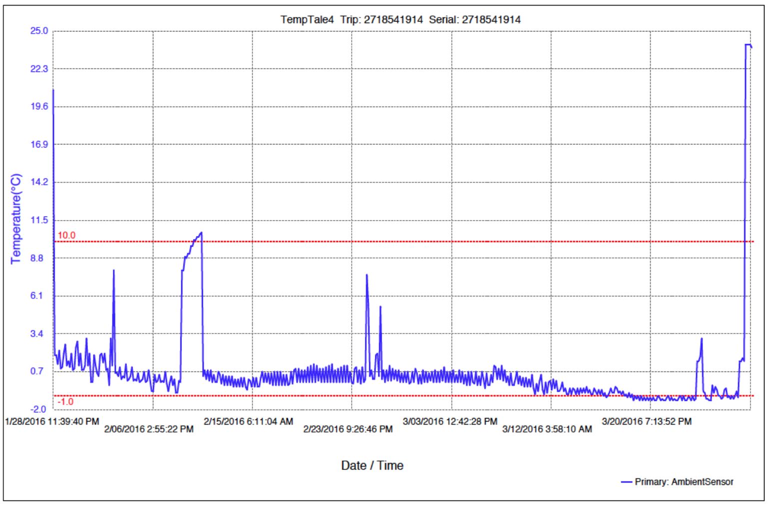


Fig 16: Temperature:time profile of a container of VP beef consigned between Australia and Rotterdam (The Netherlands)

7.4 Slow steaming

The introduction of slow steaming occurred after the Global Financial Crisis due to two main drivers: an oversupply of vessels during an international downturn of trade, plus high costs of fuel (Fig 17). At peak oil prices, fuel costs accounted for as much as 50% of total sailing costs and lowering engine speed by

10% was able to reduce overall energy for the voyage by 19% (Kloch, 2013).

In 2009, the container line, Maersk, cut the average speed of its vessels from 20 knots to 17 knots, with the possibility of cutting to 12-16 knots, a speed perhaps ironically slightly slower than that of the tea clippers of the 1800s.

The pluses for slow steaming rest entirely with the shippers which, because of longer steaming times, are able to have more vessels at sea at any one time, instead of having to lay-up vessels; one downside is that engine wear may be more pronounced – slow steaming has been likened to driving a car uphill in top gear (Anon. 2012).

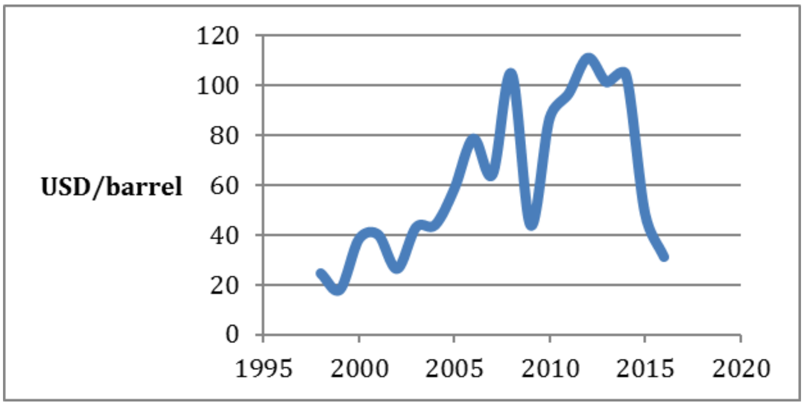


Fig 17: Price (US$) West Texas Intermediate crude oil

For suppliers, slow steaming has introduced problems, not just for suppliers of perishable foods, by reducing remaining shelf life, but also for those companies which rely on Just-in-Time (JIT) supply of components e.g. the automobile industry.

Mills et al. (2014) highlighted the impact of exporting vacuum-packed lamb primals from New Zealand to Europe citing the impact of slow steaming as extending the voyage by about one week to 53-56 days, constituting a significant proportion of the storage life of the 60-70 days estimated at -1.5°C (Bell, 2001; James & James, 2002). As can be seen from Appendix 1.5 major shipping lines cite voyage lengths from Australia to Europe which accord exactly with the range cited by Mills et al. (2014).

The present study, by contrast, established an average establishment chiller to customer chiller time to the UK of 47.1 days (range 45-54 days) with actual voyage times around 37 days, based on data logger information.

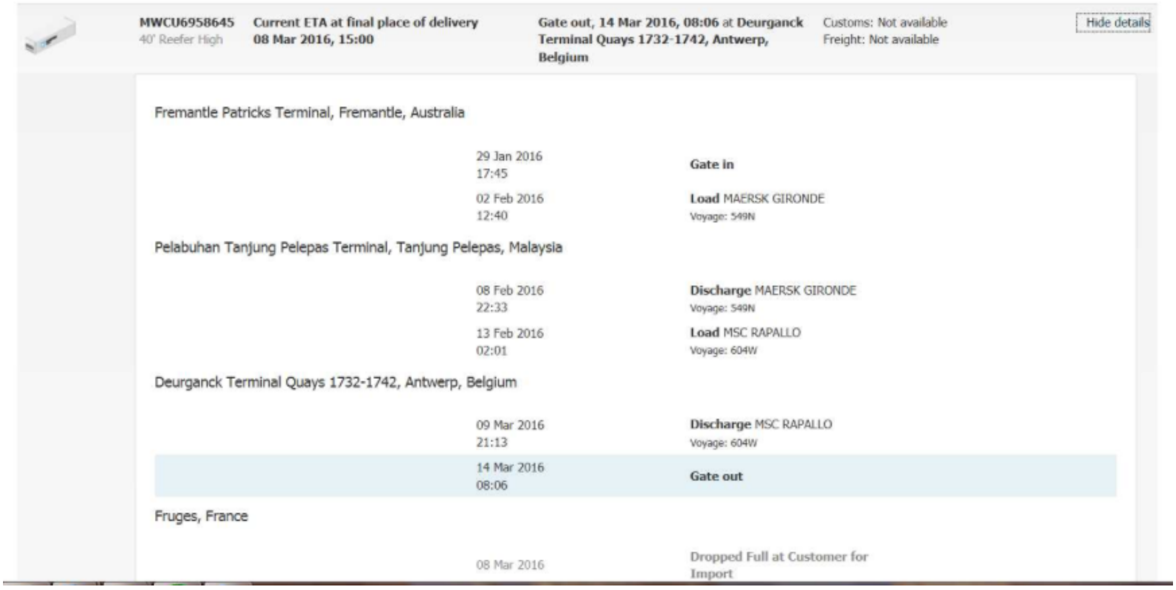
Shipping to continental Europe can be as short as 34 days between Fremantle and Le Havre, based on tracking information indicated in Fig 18; East coast Australian ports will take about one week longer.

Fig 18: Typical tracking information of consignment

7.5 Journeys extended by disputes or extended trans-shipment times

The effect of industrial disputation has already been illustrated in Section 4, where, in a dispute on the West coast of the USA, total voyage length (from establishment cold store to clearing) was around 10 days longer during the dispute, compared with "normal" clearing.

Trans shipment at intermediate ports, or clearing at the destination port can also reduce the shelf life available to the customer. In Fig 19 is presented tracking information of a consignment from Fremantle to France in which five days were required for trans shipment in Tanjung Pelepas and a further five days for clearing at the destination port (Antwerp, Belgium).


MWCU6958645
40' Reefer High
Current ETA at final place of delivery
08 Mar 2016, 15:00
Gate out, 14 Mar 2016, 08:06 at Deurganck Terminal Quays 1732-1742, Antwerp, Belgium
Customs: Not available
Freight: Not available
Hide details

Fremantle Patricks Terminal, Fremantle, Australia

29 Jan 2016 17:45	Gate in
02 Feb 2016 12:40	Load MAERSK GIRONDE Voyage: 549N

Pelabuhan Tanjung Pelepas Terminal, Tanjung Pelepas, Malaysia

08 Feb 2016 22:33	Discharge MAERSK GIRONDE Voyage: 549N
13 Feb 2016 02:01	Load MSC RAPALLO Voyage: 604W

Deurganck Terminal Quays 1732-1742, Antwerp, Belgium

09 Mar 2016 21:13	Discharge MSC RAPALLO Voyage: 604W
14 Mar 2016 08:06	Gate out

Fruges, France

08 Mar 2016	Dropped Full at Customer for Import

Fig 19: Tracking information illustrating how trans-shipment and clearing reduce shelf life

7.6 Container set point delivers "warm" temperature over whole voyage

For a container to receive air at the required temperature a number of criteria have to operate (Table 20). In addition the container's floor drains must be free, the insulation in visibly good condition and the door seals complete and in good condition.

Table 20: Typical specifications for a refrigerated container

Thermostat setting	-1.0°C
Box reading delivery /return air temp.	-1.0°C/-0.2°C
Actual temperature of thermostat sensor	In line with the displayed temperature
Manual defrosting	Functioning as required
Automatic defrosting	Functioning as required
Evaporator	Air flow unobstructed
Evaporator fans	Functioning as required

Condenser	Air flow unobstructed
Condenser fan	Functioning as required
Refrigerant	Sufficiently charged

In Table 21 are presented summary data describing the effect of “warm” container temperatures during long voyages. The effect is most marked with VP lamb primals, with average temperatures which may seem acceptable to the industry (<2°C) nonetheless compromising available shelf life in a retail cold chain at an average of 4°C.

Table 21: Examples of “warm” container temperatures and effect on shelf life available to the customer at 4°C

Product/Destination	Lamb/Europe	Lamb/Middle East	Beef/USA
Voyage length (d)	48	31	47
Average temperature on voyage (°C)	1.9	1.9	1.2
Final bacterial level (log cfu/cm2)	8	8	8
Shelf life remaining at 4°C (d)	0	6	2

7.7 Macro temperature abuse during airfreight

Occasionally, human error results in a container not being connected properly to power, with ensuing lack of refrigeration, such as illustrated in Fig 20 where product was not refrigerated between Australia and Singapore.

According to the UTas Predictor shelf life would have been exhausted around February 14th, about 10 days after loading aboard the vessel. During trans shipment in Singapore the temperature was restored to the container, but too late to save product, which had to be condemned.

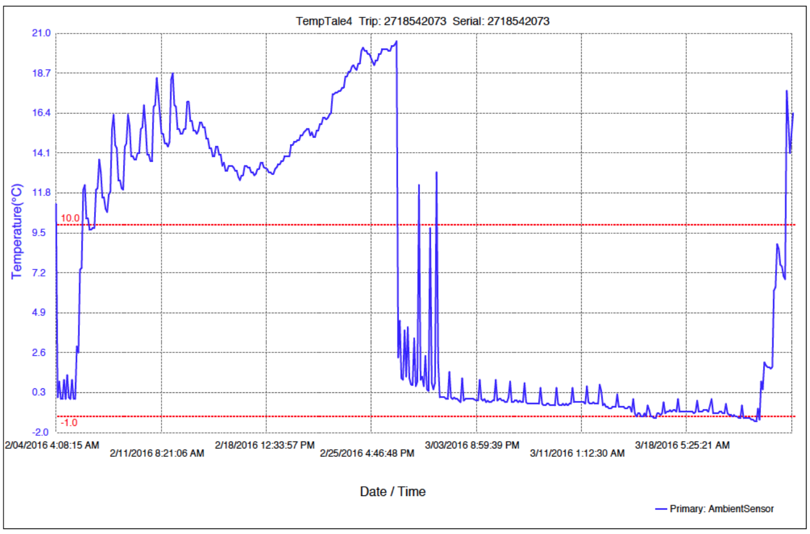


Fig 20: Temperature profile of a container lacking refrigeration between Australia and Singapore

Air freight consignments receive dry ice to chill the air surrounding product, to which end it is added in containers (see Fig 4). Dry ice has a temperature of -35°C and, as can be seen from Fig 21, if it is not added properly it will freeze meat for much of the transport time.

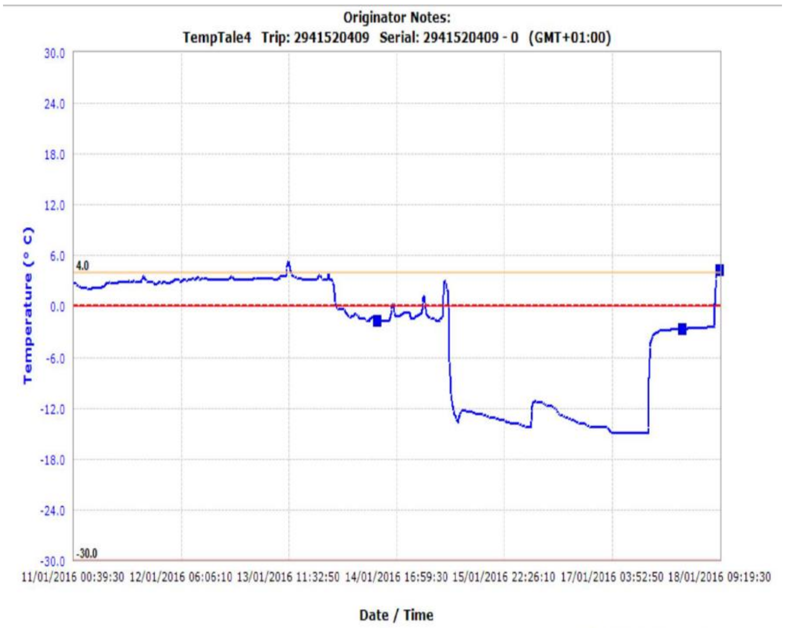


Fig 21: Incorrect addition of dry ice to a consignment of VP meat to Europe

8.0 Conclusions/ Recommendations

Around 200 data loggers were interrogated for the present study, the vast majority of which indicated satisfactory temperature:time relationships over the preloading, voyage and clearing phases, which would allow ample remaining shelf life for marketing in the importing country.

Occasional departures from the norm occurred due to one or more the seven elements identified in Section 6.0, with most centering on temperature abuse due to human error, ranging from failure to operate a container at the required set point to not providing power to the container.

In general, the industry does not require their connection in the importing country to download data from a logger unless there has been a substantial failure resulting in obvious loss of quality. Thus current use is confined exclusively to establishing liability in insurance claims and, while this is a perfectly suitable use of the logger, companies could enhance their investment in the technology by establishing a database to various markets.

Also, on a company basis, value could be added to the logger output by integrating it with the microbiological profile of different cuts. At present companies have limited information on high-value cuts such as striploins, rumps and cube rolls but with the burgeoning Chinese market requiring a higher proportion of lower-value cuts (e.g. flanks and briskets), coupled with potential distribution problems in that country, it would be prudent for companies to:

1. Obtain microbiological profiles of various cuts
2. Carry out shelf life trials on these cuts under controlled conditions in the company cold store
3. Focus on obtaining download data from importers, particularly in China
4. Relate top-end counts on various cuts with the range of temperature:time data profiles obtained from the importer

Supply to the Chinese market is expected to increase greatly and it would be prudent to revisit the type of information produced in the present study in the medium term. Such a study might be expected to identify potential problems which could be mitigated before such problems manifest themselves.

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10.0 Appendices: Major routes and shipping schedules

10.1 Australia to China

Maersk Line and Hamburg Süd operate shipping routes via Kaohsiung (Taiwan) linking Australian and Chinese ports, with shipping times of 20 days from Melbourne (Table A1).

Table A1: Maersk Line and Hamburg Süd shipping routes linking Australia-China

	Days	
	Maersk	Hamburg Süd
Melbourne	0	0
Sydney	2	3
Brisbane	5	5
Kaohsiung	18	17
Hong Kong	19	-
Yantian	20	20

10.2 Australia to Japan, South Korea and China

Maersk Line and Hamburg Süd also link Australian and Chinese ports via Japan and South Korea (Table A2 and Fig A1), with meat reaching a final destination in Ningbo in 28 days from Adelaide or 35 days from Fremantle.

Table A2: Maersk Line and Hamburg Süd shipping routes linking Australia-China via Japanese and South Korean ports

	Days	
	Maersk	Hamburg Süd
Fremantle	0	-
Adelaide	6	0
Melbourne	9	3
Sydney	12	7
Brisbane	14	9
Yokohama	26	19
Osaka	27	21

Busan	29	23
Qingdao	32	25
Shanghai (Yantian)	34	27
Ningbo	35	28

A service is operated by Hapag Lloyd, which ships product from Melbourne to Ningbo in 25 days (Table A3).

In terms of shipping a container of meat to Chinese ports there are numerous lines which provide service without trans-shipment, a desirable attribute because the supplier can rely on the date of arrival. As will be seen later, trans-shipment from vessel one to vessel two may be prevented because bad weather or mechanical problems intervene, causing the container to await the next available container ship plying the desired rout (often a delay of one week).

Table A3: Hapag Lloyd route Australia-China via Japanese and South Korean ports

	Days
Melbourne	0
Sydney	3
Brisbane	5
Yokohama	16
Osaka	18
Busan	20
Qingdao	22
Shanghai (Yantian)	24
Ningbo	25

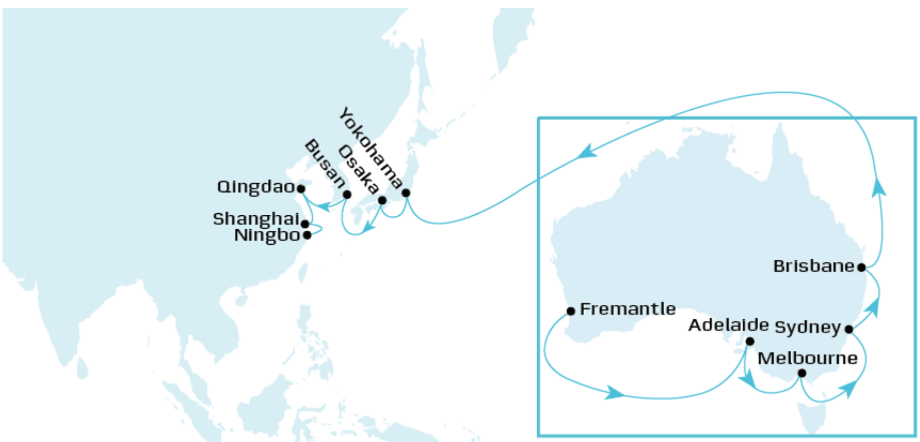

Fig A1: Shipping between Australian and Chinese ports via Japanese and South Korean ports

10.3 Australia to USA (West coast)

Hapag Lloyd have a route to the west coast of USA are via New Zealand with arrival from Melbourne at Oakland and Long Beach after 24 and 27 days, respectively (Table A4).

Table A4: Hapag Lloyd route linking Australia with West coast USA

To/from (days)	Oakland	Long Beach
Melbourne	24	27
Sydney	21	24
Tauranga	17	20

The same company also has a route linking with ports in British Columbia, Washington State and California extending the voyage by nine days (Table A5).

Table A5: Hapag Lloyd route linking Australia with West coast USA and Canada

To/from (days)	Honolulu	Vancouver	Tacoma	Oakland	Long Beach
Sydney	21	28	30	33	35
Melbourne	19	26	28	31	33
Adelaide	17	24	26	29	31

Hamburg Süd also services the West coast of USA and Canada via Fiji with voyage times similar to those of Hapag Lloyd (Table A6).

Table A6: Hapag Lloyd route linking Australia with West coast USA and Canada

	Days
Sydney	0
Melbourne	2
Auckland	10
Suva	14
Vancouver	28
Tacoma	30
Oakland	33
Long Beach	35

Maersk offer a service to the West coast of USA and Canada, though trans-shipment in Yokohama adds two days to the voyage (Table A7).

Table A7: Hapag Lloyd route linking Australia with West coast USA and Canada

To/from (days)	Long Beach	Oakland	Seattle	Vancouver
Brisbane	24*	27*	28	30
Sydney	28*	31*	31	34
Melbourne	31*	34*	35	38
Fremantle	34	40	38	41

* Yokohama trans-shipment

10.4 Australia to USA (East coast)

A direct route to the East coast of the USA is available with Hapag Lloyd, via New Zealand ports (Table A8) with a voyage time from Sydney to Philadelphia of 38 days.

Table A8: Hapag Lloyd route linking Australia with East coast USA

To/from (days)	Philadelphia	Charleston
Sydney	38	41
Melbourne	35	38
Port Chalmers	30	33
Napier	28	31
Tauranga	26	29
Auckland	25	28

Marfret also services East coast USA with a direct voyage of 37 days from Sydney to Philadelphia (Table A9), with onward shipping aboard the same vessel to Europe.

Table A9: Marfret route linking Australia with East coast USA

	Days
Sydney	0
Melbourne	2
Wellington	8
Tauranga	10
Napier	12
Lyttleton	13

Savannah	34
Philadelphia	37

Maersk (Fig A2) and Hamburg Süd offer services to Philadelphia via New Zealand ports with voyage times of 37 and 38 days, respectively with Maersk also docking en route at Manzanillo (Mexico), and Hamburg Süd at Manzanillo and Cartagena (Colombia) where trans-shipment to Europe is also possible.

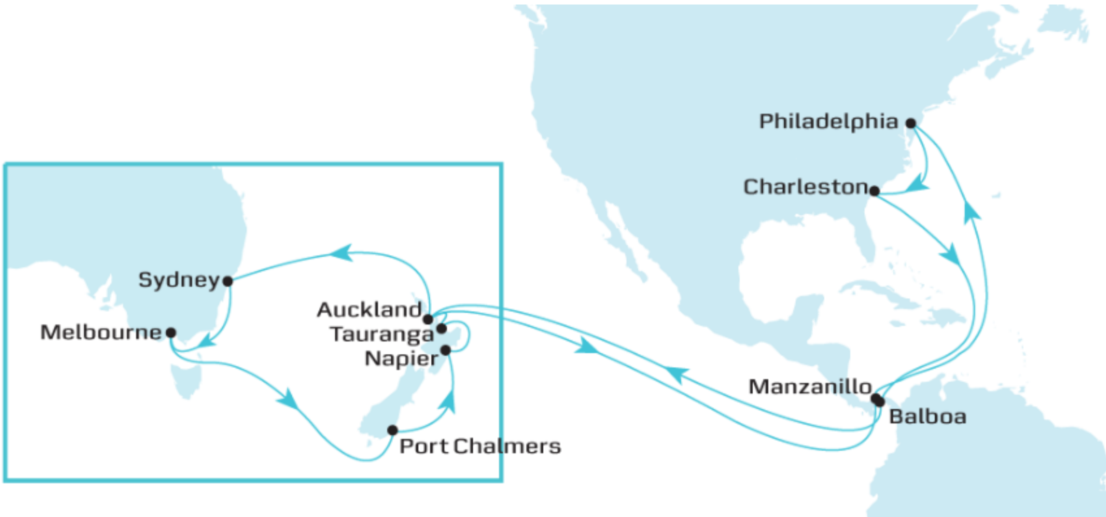

Fig A2: Maersk Line routes to East coast USA

10.5 Australia to Europe

Hapag Lloyd have a direct route from Australia to Europe, docking at ports in the UK, Germany, France and The Netherlands (Table A10), the journey taking 48 days to UK and 53 days to the final destination (Le Havre).

Table A10: Hapag Lloyd route linking Australia with Europe

To/from (days)	Tilbury	Hamburg	Rotterdam	Le Havre
Fremantle	54	56	58	59
Melbourne	48	50	52	53
Sydney	45	47	49	50
Adelaide	42	44	46	47

Marfret also services Europe with a direct voyage of 50 days from Sydney to Tilbury and 54 days to Le Havre via New Zealand and East coast USA (Table A11).

Table A11: Marfret route linking Australia with via New Zealand and East coast USA (see also Table A9 for intermediate ports)

	Days

Sydney	0
Savannah	34
Philadelphia	37
Tilbury	50
Rotterdam	51
Dunkirk	53
Le Havre	54

Hamburg Süd services Australia-Europe via New Zealand and Mexican ports plus trans-shipment at Cartagena (Table A12) with similar voyage times to other shipping lines.

Table A12: Hamburg Süd route linking Australia with via New Zealand and Europe

	Days
Sydney	0
Cartagena	33
Rotterdam	48
Hamburg	50
Le Havre	52
London	53
Antwerp	54

10.6 Australia to SE Asia for trans-shipment

Major trans-shipment ports are Singapore and Tanjung Pelepas (Malaysia) with voyage times around 20 days from Sydney with Maersk (Table A13; Fig A3).

Table A13: Maersk schedule to Singapore and Tanjung Pelepas

	Days
Sydney	0
Melbourne	4
Fremantle	11
Tanjung Pelepas	19
Singapore	20

Fig A3: Maersk Line routes to Tanjung Pelepas and Singapore

10.7 Trans-shipment SE Asia to Middle East

Maersk Line services both Red Sea and Persian Gulf ports out of Tanjung Pelepas (Table A14).

Table A14: Maersk schedule from Tanjung Pelepas to Middle Eastern ports

	Days
Tanjung Pelepas	0
Colombo	2
Jebel Ali Dubai	7
Djibouti	13
Jeddah	17

Hanjin Shipping run from Singapore direct to Saudi Arabia and United Arab Emirates ports (Table A15), cutting seven daus from the Maersk Line schedule to Jeddah.

Table A15: Hanjin Shipping schedule from Singapore to Middle Eastern ports

	Days
Singapore	0
Jeddah	10

Singapore	0
Jebel Ali Dubai	10
Abu Dhabi	11

10.8 Trans-shipment SE Asia to Europe

Maersk Lines run from Tanjung Pelepas to European ports via the Suez Canal, unloading at Algeciras prior to France, The Netherlands, Germany and the UK, a total voyage of 27 days (Table A15; Fig A4).

Table A15: Maersk Line schedule from Tanjung Pelepas to Europe

	Days
Tanjung Pelepas	0
Suez	9
Algeciras	14
Le Havre	18
Rotterdam	21
Bremerhaven	24
Felixstowe	27

Fig A4: Maersk Line route to Europe from Tanjung Pelepas

Shipping to from Australia to Europe via Singapore or Tanjung Pelepas involves less sea time than shipping via the Panama Canal and East coast USA. However, there may be downtime in the trans-shipment port awaiting the onward vessel.

10.9 Australia to Japan and South Korea

Maersk Line and Hamburg Süd operate services from Australian ports to ports in Japan and South Korea (Table A16).

Table A16: Maersk Line and Hamburg Süd schedules to Japan and South Korea

	Days	
	Maersk	Hamburg Süd
Fremantle	0	-

Adelaide	6	0
Melbourne	9	3
Sydney	12	7
Brisbane	14	9
Yokohama	26	19
Osaka	27	21
Busan	29	23